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The San Gabriel-Los Angeles Transmission Plant.

BY GEO. P. LOW.

NOTE THE WOOD PIPE LINE IN THE MOUNTAIN FOREGROUND.

CANYON OF THE SAN GABRIEL RIVER.

SPEAKING generally, the business of transmitting electrical energy over long distances has settled down to fairly well defined practices, in California at least, and ordinarily, one has but to know the kind of apparatus used, whether it be General Electric, Stanley, or Westinghouse, to be able to form a close idea of the principal features of the installation. Each company has its own types of equipment that are closely adhered to in almost every case, but the engineer who essays to visit the San Gabriel transmission will do well to leave many preconceived ideas behind unless he has been advised beforehand, for, whoever he may be, he will find the work clear through from the hydraulic development to the electric distribution to be a constant series of surprises, so that it is, in an engineering sense, the very quintessence of novelty, originality and boldness of design in many of its most important features. No one will gainsay the statement that it is a liberal education to spend a week or so in unraveling the many unprecedented combinations that are being worked, or have been worked through force of circumstances, in the most interesting installation about to be described, and it is without hesitation that the writer expresses the opinion that the Azusa-Los Angeles transmission is in some respects, the most remarkable to be found on the Pacific Coast, if not in America. Of all transmissions, the San Gabriel plant resembles the Hartford installation more than any other. Each is driven by water power, each has an auxiliary steam plant, and each delivers direct current, lighting and power service from rotary converters, but while the Hartford plant has a storage battery to equalize the load factor, the San Gabriel system gives or takes 500-volt direct current from the power circuits of the Los Angeles Railway Company, thus evening the load factor and affording a reserve of practically unlimited capacity. It is in the ingenuity of the combinations that result from the use of these three plants —water, steam and railway—that the remarkable novelty of the San Gabriel system, from an electrical engineering standpoint, exists. Many other transmissions exceed the San Gabriel plant in size, line voltage and distance, but none of them can approach it in what has been aptly termed its "electrical acrobatics." Be this as it may, it is certain that the engineers have, in gymnastic parlance, always "landed on their feet," and, as a result, the engineering of the San Gabriel plant is no less thorough than that of any other transmission in the country, while, beyond that, it is in many respects without a parallel, particularly in the broad resourcefulness of its designers, who have exercised exceptionally able engineering judgment in overcoming the greatest difficulties that could possibly beset an electric transmission during a season of most trying adversity. "Water is king" is a phrase that has become proverbial in central and southern California where a few brief weeks of bounteous rain and many long months of cloundless skies necessitate the utmost care in preserving the flow of every stream of fresh water, however small, and uniting these streams into irrigation ditches. This is indeed the land of "sunshine, fruit and flowers," but as Sahara has the sunshine, some portions of California, too, would be without fruit and flowers

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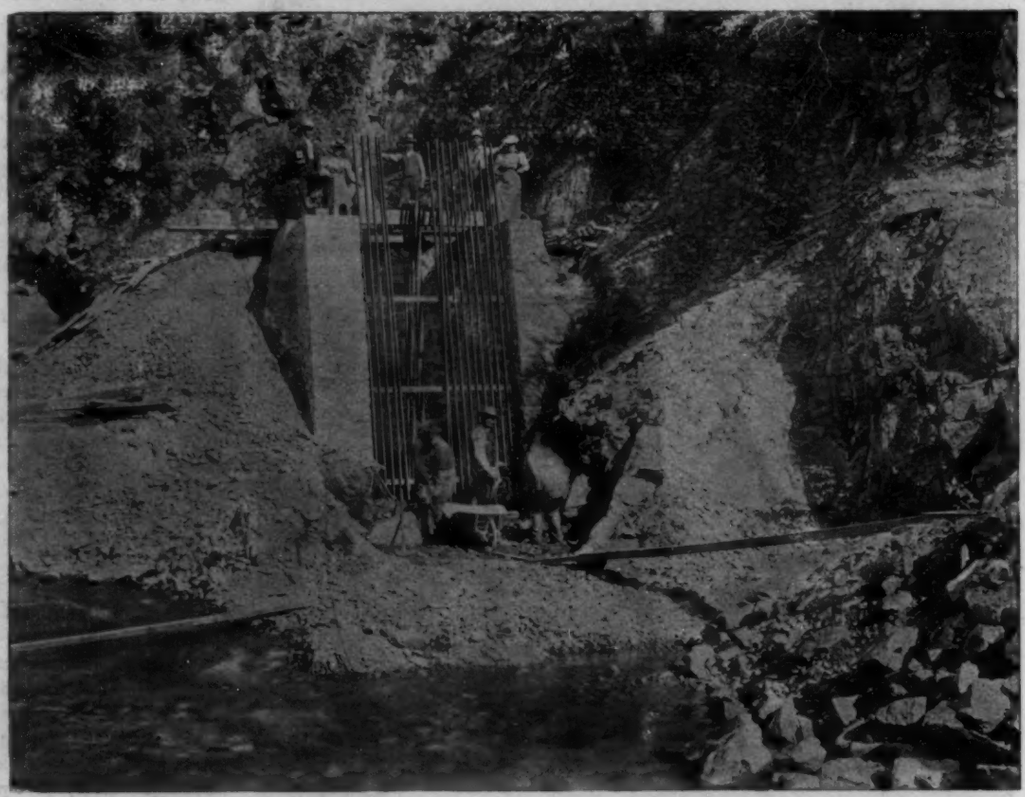
were it not for irrigation derived by untiring care and watchfulness from these self-same streams while yet in their parental mountains. Though most of the larger rivers carry surface water across the lowlands all through the year, some of them are "dry" rivers in summer; that is, during summer months the course of the river is marked by the dry, bleached gravel and granitic sand that shimmers with the heat of the sun as on the desert wastes. But a few inches below the surface is found moisture and in a few feet of digging water will seep in right merrily, while by going down stream a few yards seemingly immeasurable quantities of excellent water will be found percolating through the gravel on toward the sea. Such "dry" rivers are found only in lowland valleys, as in the mountain canyons there is surface flow all the year round, and these mountain rivers, so beautiful and innocent ordinarily, become torrential at times in winter, often rising from twenty to thirty feet or more in a single night, with waters carrying all before them in their wild rush down the canyon. It seems odd, in going up the San Gabriel canyon for instance, to drive on the dry portion of the river bed beside the flowing water and to pass under wire ropes, along which improvised cars are pulled to bridge foot passengers over at times of high water. The San Gabriel river is of this class, but rarely is the season so dry that the surface water entirely disappears down in the valley. The prudent engineer, though, gauges the capacity of a stream of water for power purposes by its minimum flow, even though that minimum be reached but once in a generation; and so, when the drouth of the present year came on, the San Gabriel company was not found unprepared for the emergency. For thirty years the water of the San Gabriel river has not been so low as during the summer just closed, nevertheless the plant began operations on July 1st, as announced, and satisfactory service has been continued ever since without a moment's interruption, despite seemingly insurmountable obstacles, among the least of which was the fact that it was a new company, with a new plant, in a new field, with new underground service delivered in part from new and untried electrical combinations. More than this, the business of the company increased so rapidly that within a month after operations commenced, the rated capacity of the plant had been reached, whereas it was not expected that this load could be secured in less than six months. At present every piece of apparatus connected with the delivery of direct current service is being run for a few hours every Saturday night a. an overload of from fifty to sixty per cent. without evincing a sign of injury or hardly of overload.

How these satisfactory results, so briefly set forth above, have been attained, forms one of the most interesting and instructive experiences in the history of electrical transmission installation, and to faithfully describe the engineering details of the plant is the purpose of the following pages.



A 580-FOOT TUNNEL RUNS BACK FROM THIS INTAKE.

HEAD OF THE WATER SYSTEM AT THE DAM SITE.

THE WATER SYSTEM.

The width of the San Gabriel river at the head of the water system is close to four hundred feet, which measures the distance between the sides of the canyon. By wagon road, the intake is nearly nine miles from Azusa, a small station in the San Gabriel valley on the Santa Fé railroad, and eight miles from the power house, although the waterway is less than six miles in length, but the winding character of the river, along which the road follows, easily accounts for the difference. The intake is on the easterly side of the river at the base of a mountain that rises to a height of from three to four thousand feet above, and the peculiarity of the intake is that the water, after passing the strainer bars and headgates, makes a straight perpendicular drop of twenty feet, whence it continues horizontally in a southerly direction through a 580-foot tunnel, which is the first of the series of thirty-eight tunnels in the waterway. At first glance it seems as though the bringing out of the first tunnel at a point twenty feet below the level of the river at the intake must have been an error, for it reduces the head of water at the power house by that elevation; but when it is remembered that in summer time a material part of the flow of the river is in underflow that seeps through the sand and gravel beneath the river bed, and that this underflow should be thrown into the canal as well as the surface flow, the wisdom of the engineers in building the tunnel as located will not be questioned. The underflow must, then, be diverted into the tunnel, to do which a submerged dam is to be built during the coming summer across the bed of the river immediately below the intake, and during the summer just closed, shafts have been sunk across the river bed for the purpose of determining the contour of bedrock preparatory to the awarding of the contract for the building of the submerged dam.

THE SUBMERGED DAM.

These shafts are eight in number, being in line across the canyon, and fifty feet apart, and work on the sinking of two of them,

which appear to be at a location where a subterranean ravine has been cut in the bedrock, has been abandoned for the winter, but will be resumed again next spring as soon as the river is low enough to admit working. The sinking of these shafts, though troublesome, has not been an unmixed evil, for during the past

THE STAVE PIPE IS CARRIED THROUGH SHORT TUNNELS.

summer from two hundred to two hundred and fifty inches of water have been lifted therefrom at a depth of about thirty feet, and the water thus raised has been thrown into the canal. This has been a material gain, as the water reaches the power house under a head of four hundred feet, and as the pumping at the dam site has been done by steam, with drift wood as fuel, making the cost of pumping very low. Bedrock has been reached in all but two of the shafts, and its average depth for the remaining six shafts is slightly above twenty feet. No doubt is felt but that bedrock will be found in the two shafts referred to at depths of less than sixty feet, in which event some sixty or seventy-five feet of the length of the dam will have an average height, or rather depth, of fifty feet, while the remaining three hundred odd feet of the dam will have an average depth of not more than twenty-five feet.

The dam so constructed will be of concrete with an average thickness of perhaps twenty feet at the base, tapering to a width of probably six feet at the top; this top or crest, of course, being level with the surface of the gravel that forms the bed of the river. The engineer's plans show that the dam is to have a radius of four hundred feet and that a catchment tunnel will be constructed along its inner surface along a line on a level with the first tunnel of the water way some twenty feet below the surface of the river bed; into this catchment tunnel the underflow will seep through percolative walls whence it will be carried into the main waterway direct, and it is estimated that an increase of at least six hundred inches of water will be made available as a result of the building of the submerged dam as proposed. It is possible that the dam may be carried up to an elevation of thirty feet above the river bed, which would give a catchment area nearly four miles long, but the company's plans are not matured in this direction as yet.

A remarkable feature in the water system of the San Gabriel Electric Company is the fact that the water is carried either through concrete work, masonry, or closed pipe from beginning to end. No attempt is to be here made to give actual figures concerning any portion of the plant, as complete and accurate information of this nature will be found in the table of engineering data given at the conclusion of this article; but it is of interest to note that the water system contains over twenty thousand feet of tunnels, nearly nine thousand feet of wood pipe, and over fifteen hundred feet of concrete culvert. No open ditching, in the ordinary sense of the term, is used, and the system has no fluming; the tunnels are lined on the sides and bottom with concrete varying from four inches up to thirty-six inches in thickness, according to the characteristics of the rock, and, except where firm rock is pierced, the tunnels are arched with masonry. The

A SUPERB WATERWAY.

mountains are mainly of decomposed granite, and one tunnel that had a length of above two hundred feet, was found to be filled with loose, finely broken rock—just about as rock comes through a rock breaker—although for two rods at each end of the tunnel the rock was of ordinary kind. Naturally, the piercing of a tunnel through such formation was found to be a very difficult piece of work. The longest tunnel in the system has a length of 1610 feet, several hundred feet of which are run within from fifteen to fifty feet of the perpendicular wall of the canyon, and in cutting this tunnel work was commenced simultaneously at five different points, viz.: at the two ends and at three points in the canyon from which lateral tunnels were run in the proper distance whence work on the main tunnel was continued at right angles thereto. So far as is known there is no leakage whatever in any portion of the waterway, and, to the contrary, there is an in-seepage into the tunnels at points that are not arched which amounted at no time during last summer to less than twenty-five inches; in other words, at least twenty-five inches more water reached the power house than was turned into the intake at the dam site, but this is not suprising to one who has investigated the extraordinary thoroughness of the waterway construction; even the pores of the concrete have been filled with a penetrating compound to prevent loss of water. Where open ditches would ordinarily be run, wood stave pipe and arched culverts have been used, and with the exception of a very few rods of open concrete ditching, the only

ALL STAVES BREAK JOINTS AS SHOWN ABOVE.

points along the waterway where evaporation is possible are at the sand gate, penstock, and at the ends of the wood stave pipe line. Indeed, so perfectly constructed is the company's water system that the Duarte and Azusa irrigation districts, which hold the prior right to the waters of the San Gabriel river, have granted

to the San Gabriel Electric Company the perpetual ownership of one-tenth of the flow of the river in consideration of the thoroughness of the water development. The value of this grant will be recognized when the fact is known that in that section of southern California water has a value of $1000 a miners inch.

The exceedingly broken and rough character of the canyon made the problem of designing an economical water conduit that

AT EACH END OF PIPE LINE THE WATERWAY DROPS.

should be tight, permanent, and not subject to injury or interruption, a difficult one to solve, for such were the requirements for the waterway in that portion of the system outside of the tunnels; nevertheless the engineers succeeded in finding a most satisfactory solution of the question in the use of wood stave pipe.

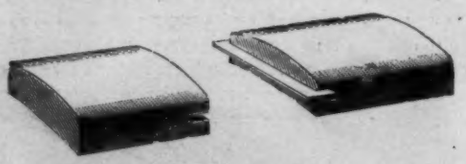
WOOD STAVE PIPE.

All pipe, except the last short section leading down from the penstock to the power house, is 48-inch wooden stave pipe, laid uniformly ten feet below hydraulic grade, and is buried in the side of the mountain. As this kind of pipe has earned its place among the recognized and approved standards in the western United States, and has, owing to its comparatively low cost, made many propositions financially possible that could not otherwise have been carried out, and as it may not be so well known

A CHARACTERISTIC BIT OF MASONRY.

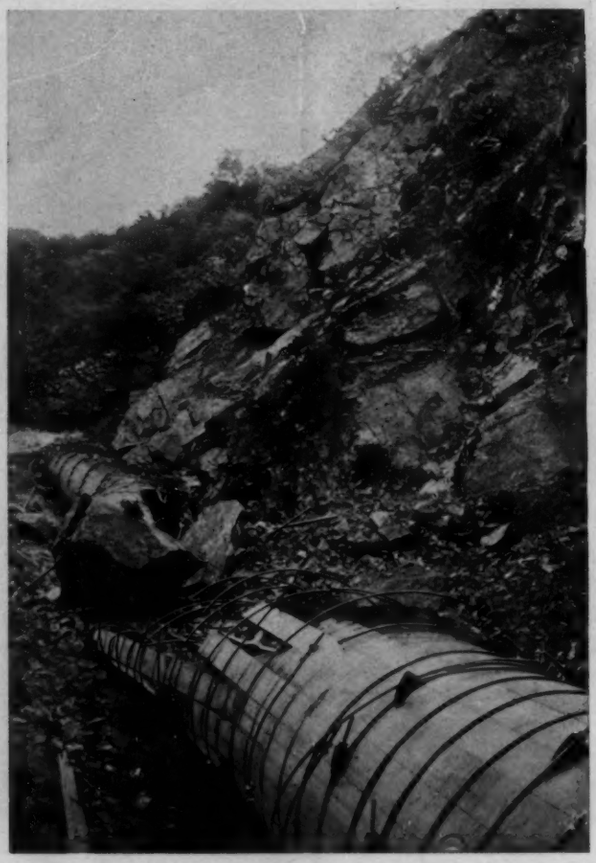
outside of the section of the country where it originated, a detailed statement of its construction and merits will, it is believed, be welcomed.

The pipe is a continuous cylindrical tube consisting of wooden staves, placed so as to break joint, and derives its strength and rigidity from the steel hoops surrounding it. The staves are of clear wood, usually California redwood, dressed on the flat sides to circles and on the edges to radial planes, a certain number completing a true circular ring, thus forming the shell of the pipe. The staves are cut off square and the ends are slotted for the insertion of a metallic tongue, as shown in the adjoining cuts. The



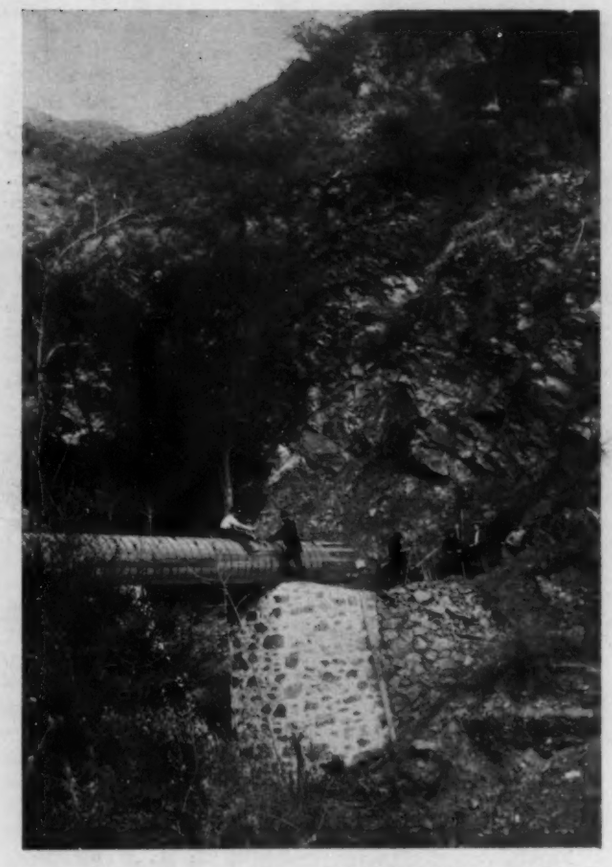
width of the slot is a little less than the thickness of the tongue, and the depth is less than half its width, so that when in place and with staves abutting, the edges of the tongue cut into the bottom of the slots and into the sides of the adjoining staves, thus securing a tight butt joint.

The bands consist of round steel bolts or rods, with a head at one end and a thread, nut and washer at the other end, the two ends being united by a malleable iron shoe. The bolt has a cold



IT COST ONLY $14.60 TO REPAIR THIS BREAK.

pressed thread of greater strength than its shank. The shoe, which fits close upon the pipe, has an interior shoulder for the head of the bolt and an exterior shoulder for the nut, and is of such a shape as to leave the entire band in a plane perpendicular to the direction of the pipe. Round bands are preferable to flat ones, as, for equal strength, they expose less surface to rust and, moreover, when the wood swells, they imbed themselves into the staves more satisfactorily than flat bands. The turning of the nut tightens the band and presses the staves together, the effect being that when the bands are at proper tension a wooden cylinder is produced of great strength and which for rigidity against collapsing is only equaled by cast-iron pipe. The spacing of the bands varies, depending upon the pressure at any one point. Where the pressure is the same all along the spacing remains uniform as in the San Gabriel pipe where the bands are placed ten inches center to center. The pipe can be laid in curves the radius of



HOW THE RAVINES ARE CROSSED.

which depends upon the diameter of the pipe and the thickness of the staves. The sharpest of the curves of the San Gabriel pipe have a radius of 125 feet. Where sharper curvature could not be avoided, steel elbows were introduced of slightly larger diameter, having a riveted bell or socket to connect with the wooden pipe, the space between the pipe and bell being partly filled with oakum, driven in hard, the remainder being filled with clear Portland cement as shown in the accompanying sectional drawing.

Connection is made between the pipe and each tunnel by means of a small masonry basin with its bottom sloping from the grade of the tunnel to the grade of pipe ten feet lower. The water in these basins stands always well above the top of the pipe, and even when the flow ceases altogether, the pipe remains entirely filled and under pressure, While the pressure upon the San Gabriel pipe is very light, it should be stated, for the full understanding of this subject, that wooden pipe can be built for pressures up to 200 feet and that many heavy pressure pipes are now in successful use. Further, that when carefully designed and constructed wood stave pipe has a record for entire absence of leakage unsurpassed by any other class, as has been fully established by accurate measurements on long lines of pipe.

DETAILS OF THE STEEL AND STAVE PIPE JOINTS.

In a paper on wooden stave pipe, by A. L. Adams, appearing in the Proceedings of the American Society of Civil Engineers, for September, 1898, the relative standing of the principal qualifications governing the economy of different classes of pipe is set forth in the following table:

	COST.	LIFE.	CAPACITY.
1	Stave	Cast Iron	Stave
2	Steel Riveted	Stave	Cast Iron
3	Cast Iron	Steel Riveted	Steel Riveted

and the reasons for this classification are there fully explained. That stave pipe promises a far longer life than steel riveted pipe is explained by the fact that the staves remain at all times saturated and will last indefinitely, thus leaving the steel hoops as the only perishable portion of the pipe; that the steel in the hoops occurs in a concentrated form which exposes but little surface for rusting, the opposite being the case in the plates of a riveted pipe, and that a riveted pipe usually becomes useless and must

STEEL PIPE IS USED AT BENDS.

A COMPOUND CURVE ON THE WOOD PIPE LINE.

The construction of this pipe is apparently quite simple, but years of experience have proven that great skill and conscientious care are required to produce water-tight work and that there are a great many niceties to be observed in construction which make all the difference between success and failure.

be abandoned when less than one per cent. of the metal is rusted away because this loss occurs in small pitholes, causing leakage through the pipe, while the hoops on the wooden pipe may suffer a loss of seventy-five per cent. before leakage would result. Mr. Adams further publishes a table of cost for the three different

ALL MASONRY IS OF MOST SUBSTANTIAL CHARACTER.

FROM TUNNEL TO CULVERT.

classes of pipe considered, clearly showing the difference in favor of wooden stave pipe. No general tabulation of this kind can take into consideration all circumstances governing economy, and special cases will often develop further advantages in the use of wooden pipe, sometimes more or less unexpected. Take the San Gabriel pipe line as an instance. It is located on the steep side of a canyon at an elevation of from 20 to 450 feet above the stream. Clearly it would have been an expensive proceeding to hoist heavy lengths of riveted pipe to the line of ditch. The heaviest single part of the wooden pipe did not exceed fifty pounds in weight, and the load on the temporary tramways, laid on the mountain side, could be made as small as desired and men could readily carry or truck all material from the head of the tram along the grade.

During construction and before the pipe could be back-filled, or had been filled with water, a boulder on the mountain slope above became loosened and struck on top of the pipe, as illustrated on page 84. The boulder weighed many tons, the view having been taken after about two-thirds of it had been blasted away. All tramways and tools had been removed, and had riveted pipe been used it would have been very tedious and expensive to make repairs. The accident occurred on January 24th last; work on the repairs of the pipe was commenced on the day following and completed January 26th at a total labor cost for pipe work of $14.60. All but two of the bands could be used again, new staves were easily carried up the mountain sides and the undamaged portions of many of the old staves were sawed off and used in building the pipe further down the line.

The carrying capacity is another item that greatly affects economy and is too often entirely ignored in comparisons of first cost. As compared to *new* riveted pipe, stave pipe will carry from ten to forty per cent. more water, the difference being greatest for large size pipe. This difference in favor of wooden stave pipe becomes still more important after some years of use when the wooden pipe shows no diminution of flow, and a riveted pipe, by reason of tuberculation, may easily lose twenty per cent. of its original capacity. A wooden pipe, then, consumes less head in friction, thus leaving more pressure available at the wheel, or it may be made of smaller diameter to do the same work as a riveted pipe.

In comparison with flume, wooden pipe will generally be found to be more expensive in first cost, unless the flume requires trestling, but the two cannot reasonably be placed on the same basis, for while the pipe has an insured life measured in scores of years, the flume requires constant renewal. By reason of its liability to injury and necessity of frequent repairs, the flume cannot but be looked upon as a most objectionable link in a water power plant where interruption is the one thing to be guarded against. There is the further objection to flumes that they constantly leak and that the exposed water surface causes losses from evaporation, which may become serious matters where the water has to be conducted for great distances.

No doubt whatever exists then, that the use of tunnels and pipes on this extremely rocky and steep mountain side is a great advantage over the customary flume and ditch, since they are not so likely to be disturbed by falling rock, land slides, washouts, etc. In this, as in every other portion of the plant, no expense has been spared to make everything of the highest quality. The engineering and materials have been of the best throughout, and the long life of every portion of the plant will prove the wisdom of the use of such uncommonly excellent materials and workmanship.

The forebay is located on the side of a steep mountain that forms the easterly side of the mouth of the canyon, and the pipe line that carries the water thence to the power house, a little over eight hundred feet below, is of thirty-six-inch double-riveted steel, thoroughly anchored in cement abutments and laid in an air line

OVERLOOKING THE MOUTH OF SAN GABRIEL CANYON.

CONCRETE WORK AT THE PENSTOCK.

over its entire length until the power house is reached. There it turns at a right angle through a quadrant having a radius of fifty feet, running into and parallel with the lower side of the power house where it extends into a receiver of half-inch riveted steel. No air chamber is used, but instead, the receiver is supplied with two three-inch relief valves. The gradient of the pressure pipe line from the penstock to the power house is very steep, reaching in places to above fifty degrees. At the left, in the engraving below, is shown the wooden flume which carries surplus water from the penstock to the permanent weir in the tail race.

THE POWER HOUSE.

It is singular how abruptly in many places throughout southern California the low lands terminate and the mountains begin. About one mile to the north of Azusa is the power house, still

PRESSURE PIPE LINE DOWN THE CENTER; OVERFLOW WEIR AND RACE AT THE LEFT.

SAN GABRIEL POWER HOUSE, AZUSA, CALIFORNIA.

down in San Gabriel valley proper, while its penstock, eight hundred odd feet distant by way of the pipe line, is up on the mountain side. Drawing One gives a comprehensive idea of the arrangement of the power house, from which it will be seen that it is composed of three apartments extending in the direction of its length. The apartment furthest from the mountain side contains nothing but the impulse water wheels with their gate valves, regulator hoods and housings, and the receiver. The center of the building, which forms the main portion, contains the generators, exciters, switchboards, and water wheel governors, while the third apartment, constituting the transformer house, contains the raising transformers, high tension switching devices, lightning arresters and choke coils, and from this room the line wires are carried out through a usual form of opening. A gable roof covers the whole power house, and in the center apartment, where the roof is highest, a traveling crane of sufficient capacity to handle any of the machinery, is installed. All walls of the power house, even the two inner ones dividing the building into compartments, are of massive concrete work, and as the roof is of corrugated iron supported on iron trusses, the building is both substantial and thoroughly fire proof. It is, withal, one of the best arranged power houses to be found on the Pacific Coast.

The receiver presents two features which, though not innovations, are unusual in electric transmission work; viz.: it is placed along the sides of the wheels, instead of above, and the nozzles are taken at right angles from laterals which are also at right angles to the receiver. These laterals are, moreover, supported in masonry at each end, and the idea which led to this departure from conventional practices was that it would eliminate the so-called warping strains due to the placing of goose necks on the under side of the receiver. As installed, all strains from the jets are taken by masonry in direct lines so as to relieve the receiver therefrom entirely. A further feature of interest is the fact that four double sets of Tutthill water wheels are used, and as the installation is the first large electric transmission to be so equipped, the wheels call for more than passing reference. The ground floor plan of the station, seen in Drawing One, shows that the four sets of water wheels are installed with their shafts parallel and extending through a concrete wall, each for direct coupling to its respective generator. Each wheel shaft carries a three-ton fly wheel placed next to the wall, and each set consists of two wheels, each supplied from an individual nozzle, and controlled by an independent gate valve; two of the sets are provided

TUTTHILL WATER WHEELS.

SHOWING RECEIVER, BUCKET, AND FLY WHEEL ARRANGEMENT.

HYDRAULIC WORK DURING CONSTRUCTION.

with cut-off hoods in addition. The controlling valves are arranged with slow-moving worm gears so that they can not be suddenly shut off, thus rendering water hammer improbable. No further wheel equipment has been placed in this section of the station. The receiver has no air chamber, but is provided with two three-inch safety valves, a manhole, and a mud blow-off valve.

A clear idea of the water wheel equipment will be had by reference to the illustrations on page 90. The cast iron framing around the inner bearing in the lower cut, shows the line of the dividing wall, between which and the wheel casing the fly wheel intervenes. The two hand wheels in the upper left hand corner give individual control of the wheels through the gate valves; the governor is driven from the main shaft by two lines of belting; a flexible coupling is afforded through the usual form of rawhide links, and the bearings are self-oiling and self-aligning. The buckets, however, differ radically from those used in any other impulse wheel. The object of a water wheel of this type is, obviously, to convert the energy of a stream of water working under pressure into useful work, and to utilize this energy to its full value, the ideal bucket is so shaped that the jet section will enter the bucket without much deflection, agitation or turbulence. A small loss from heat, friction and change of angles due to the circular design of the wheel, can not be avoided, and the velocity of the water as it leaves the buckets is a material factor; hence, in seeking the highest efficiency, the bucket surface must not be at too great an angle where the jet enters, and the bucket must be of such form as will not in any way separate, agitate, flatten, or split up the jet. To the contrary, the bucket should be so curved as to avoid all corners or sharp angles; it should be amply deep and of such form that when the jet enters the bucket, the bucket will still hold the full section of the stream until its energy is converted into motion, when the water should be discharged without velocity and without any interference with the water from another bucket or any barrier whatever. The construction of the Tutthill water wheel bucket is such that it embodies all of these features as near as it is possible to do so and still be consistent with the best mechanical practices. The number of buckets as well as the wetted surface, is small, and hence the friction is smaller than in any other bucket of the same class. The discharge lip is parallel to the rim, and, when run at proper speed, there is no velocity whatever to the water under discharge.

In Tutthill wheels, the buckets are made in rights and lefts and discharge alternately from each side of the wheel, thus permitting the easiest possible escape of the water. This form of construction also enables the jet to strike the bucket at a tangent without splitting, that is, at its full cross section; and herein is found a distinct advantage: for while, in the more familiar types of tangential wheels, the jet is split on entering the bucket, in the Tutthill wheel there is no loss of energy from this source.

The manufacturers claim that the Tutthill wheel has a very high efficiency, in support of which they cite a test where, with a 3 1/8-inch nozzle under a head of 390 feet, an efficiency of 85.7 per cent. was realized. Another test made with a special test wheel having a diameter of 36 inches and supplied with water from a

WATER IS FLOWING INTO THE AZUSA IRRIGATION SYSTEM.

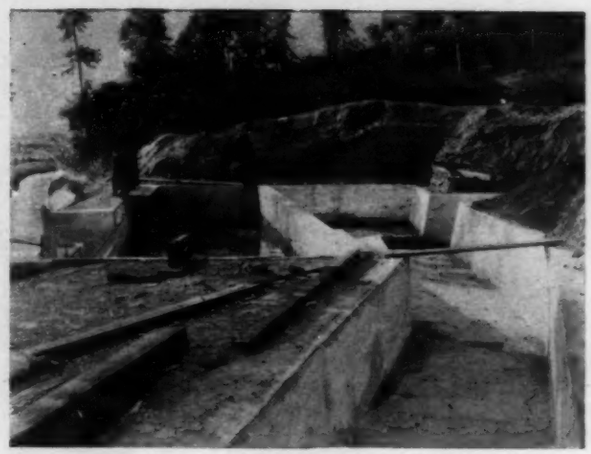
FRONT VIEW OF THE POWER HOUSE.

5/8-inch jet under a 200-foot head, is said to have given a Prony brake efficiency of 91 per cent., the wheel and shaft weighing 62 pounds. In another case a 4-inch tip under a 54-foot head is stated to have given an efficiency of 80 per cent., while under a head of 180 feet an efficiency of 85.22 per cent. is claimed when using a 2½-inch nozzle. These are, as stated, the manufacturers' claims, but in the following table is presented the results of a series of tests made by the general manager and the consulting hydraulic engineer of the San Gabriel Electric Company, and the representative of the Oakland Iron Works, which manufactures the Tutthill wheel.

Number of unit....	2	2	2	4	2	2	2	RPM
Working head.....	390	380	392	390	390	390	....	430
Static head.....	400	400	400	400	400	400	....	430
Size of tip used....	One 2 7/16-in.	Two 2 7/16-in.	One 2 5/16-in.	Two 2 5/16-in.	One 3 1/16-in.	One 3 5/16-in.	Two 3 1/16-in.	430
Cubic feet of water discharged.....	366.9	733.8	316.8	633.6	441.5	577.78	883.04	430
Theoretical h. p....	270.6	541.2	234.0	468.02	326.12	426.78	652.24	430
H'rse-p'wer output	227.30	454.60	197.30	394.6	275.2	323.4	550.4	430
Friction load of wheel in h. p....	10	10	10	10	10	10	10	430
Efficiency of wheel	84	84	83.03	84.10	84.3	84.3	85.8	430
Per cent. of load ..	50	100	35	60	60	64	125	430
Per cent. of load change in testing governor	20	50	75	100	....	....	....	430
Per cent. of variation in speed	1	1½	3	7	....	....	....	430

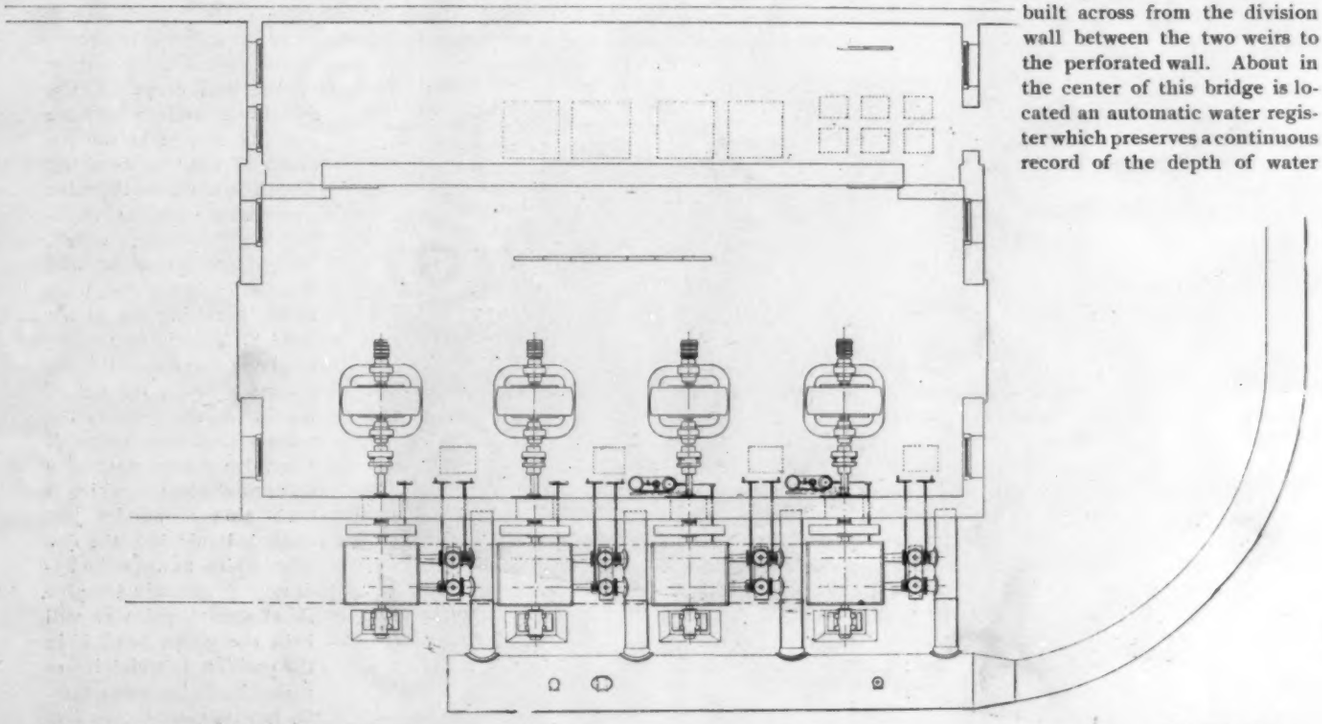
It is interesting to note, in this connection, the extraordinary degree of care that has been exercised by the engineers of the San Gabriel plant in so laying out the hydraulic system that the water delivered from the tail race to the irrigation systems below shall be under measurement at all hours of the day or night, and that these measurements shall be as accurate as it possible for human ingenuity to make them. After being used at the power house, the water is delivered to the Azusa and Duarte Irrigation districts, each in proportion to its interest in the waters of the San Gabriel river, and the contract between the San Gabriel company and these districts obligate the former to preserve the equitable division of the water, even to a fraction of an inch. To do this, some three feet in head was sacrificed in order that a weir dam could be built into the tail race.

A PERMANENT WEIR.



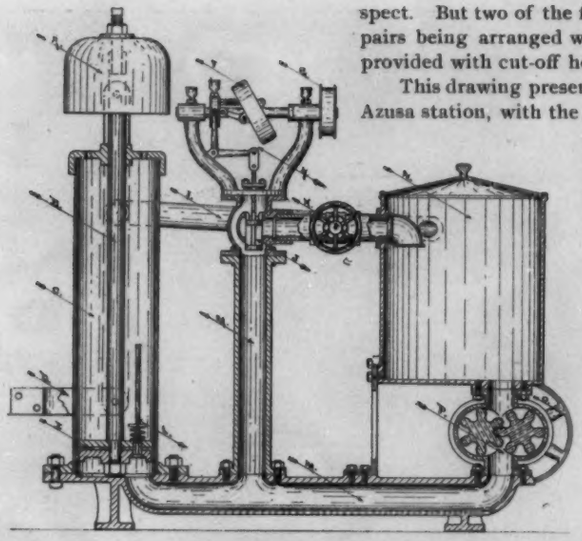
MEASURING WEIR IN THE TAIL RACE.

The above engraving shows this weir dam as it appeared before the water was turned in. The large open canal in the immediate foreground is the tail race, probably twenty feet beyond the wheel pit, and at the right near the end of this canal is the pit in which the overflow from the penstock is water-cushioned after its wild rush down the flume on the side of the mountain. Directly opposite this cushioning pit is a wall with about thirty openings placed well below the water level so that no disturbance from the water in the tail race will reach the water in the basin of the weir dam on the opposite side of the wall. This engraving, and the second one on page 88 are from photographs taken at diametrically opposite points; that above being taken from the bridge in front of the power house, and that on page 88 being taken from just beyond the head gate in the weir delivering water to the Duarte canal. The larger of the two weirs, therefore, delivers water to the Azusa district. Since the photograph was taken, a head gate has been placed on the Azusa weir as well, and a bridge-like structure has been built across from the division wall between the two weirs to the perforated wall. About in the center of this bridge is located an automatic water register which preserves a continuous record of the depth of water



FLOOR PLAN OF THE POWER HOUSE

DRAWING ONE.



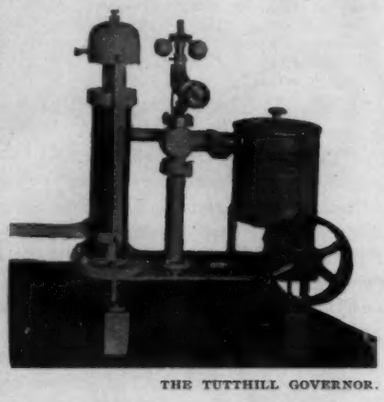
SECTION OF TUTTHILL GOVERNOR.

flowing over the weir. It shows the depth of the water without reduction on a chart that requires renewal weekly. The water used by the wheels in the test above given was measured by this permanent weir.

No one but inventors, manufacturers, and sales agents profess to believe that a perfect water wheel governor is in existence, hence every new mechanism of the kind that is placed on the market is closely scrutinized in the hope of finding an improvement in some feature on the existing forms of wheel regulator mechanisms. The Tutthill governors used in the San Gabriel power house not only possess the interesting features of newness, but they embody the highly desirable qualification of originality, simplicity and practical instantaneousness of action. It is all-mechanical and contains no delicate parts necessitating nicety of adjustment or eternal vigilance in care. While under test, the governors were subjected to violent changes of load at the Azusa power house, as will be shown, and there is a marked unanimity of opinion among the officials and employees of the company that the governor used is without a superior in any respect. But two of the four pairs of wheels are equipped with governors, the remaining two pairs being arranged with nozzles controlled by levers for hand regulation. All nozzles are provided with cut-off hoods.

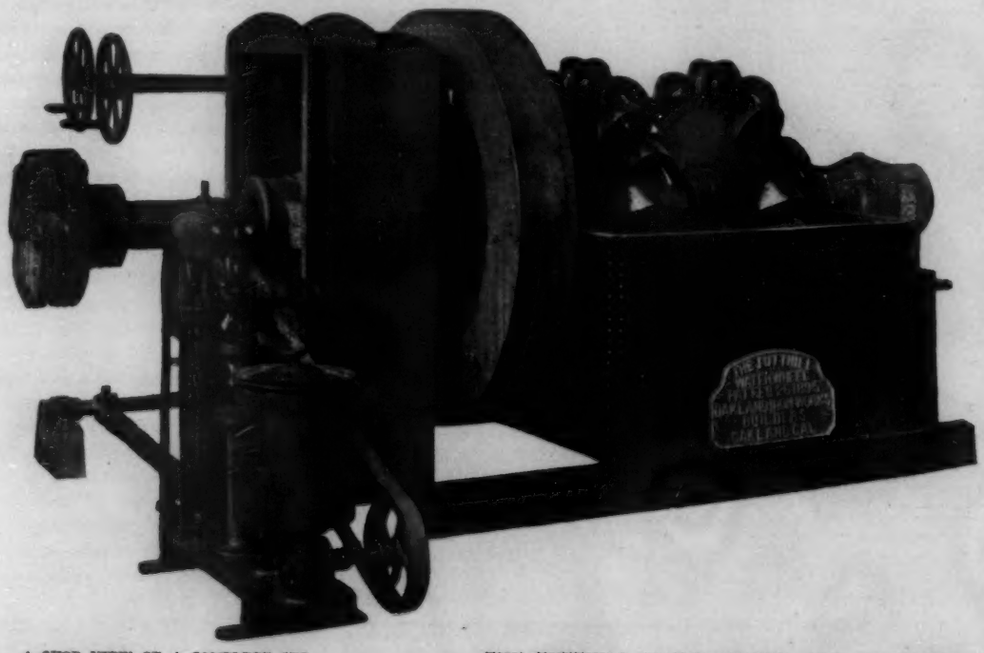
THE GOVERNOR.

This drawing presents a sectional view of the Tutthill water wheel governor as used in the Azusa station, with the exception that a tachometer type of actuating mechanism is used on the governor head, instead of the ordinary form of fly ball governor as installed. For the sake of simplicity, this governor head, carrying the parts lettered *F*, *G*, and *H*, is given a quarter turn in the sectional drawing. The piston *B*, traveling in the cylinder *C*, carries at its upper end the weight *A*, and at its lower end the plunger head *E*, while from either side of the weight *A* are long links shown in the photographs below, by means of which the motion of the piston is transmitted to the lever *D* controlling the nozzle cut-offs. Separate belts from the generator shaft drive the governor pulley *G* and the pump pulley *O*. The motions utilized in the governor head, two parts of which are lettered *F* and *H*, are practically identical with those of a tachometer, and the position of the swinging disc *F*, is transmitted by the means shown in the diagram to the valve *J*, which is under a balanced pressure by reason of the passage *I*. *N* is a reservoir containing either oil, or oil and water, or both, as preferred, and the liquid is kept in constant circulation by the pump *P* which forces it through the pipe *M* and the valve *J* back into the tank, or beneath the piston head *E*, or both, as the exigencies of governing may necessitate. Behind the valve casing is shown an overflow pipe which, as a precaution, will deliver any liquid that may get above the piston head into the tank. *K* is an ordinary gate valve which may be used, if desired, for shutting down the water wheels by means of the governor.



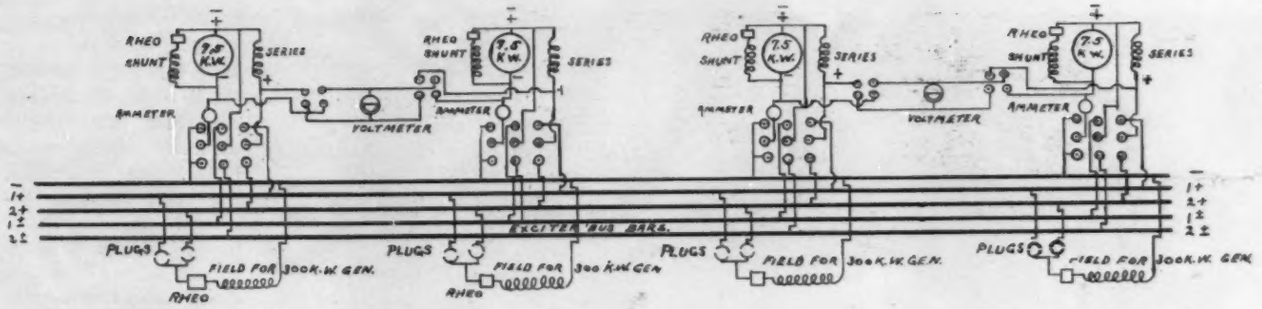
THE TUTTHILL GOVERNOR.

When the parts are in the position shown in the diagram, the cut-off hoods are entirely off the nozzle and the set of wheels is carrying a full load. The throttling valve *J*, being open, admits the passage of the entire output of the pump into the reservoir. Assuming now that a portion of the load drops off, the speed will tend to increase and the change in the position of the disc resulting therefrom will close the valve *J* proportionately, thus choking the delivery, which, being incompressible and practically irresistible, finds relief in raising the piston head *E*. This, in turn, raises the lever *D* and throttles the nozzles through the cut-off hoods. As the speed of the wheels is restored to normal, the valve *J* also returns to its normal position, which is such that it admits just enough liquid into the discharge pipe to keep the hydraulic pressure in the pipe *M* at such a point as will hold the piston head *E* in the position in which it was placed by the last movement. If, however, an increase of load should now come on re-



A SHOP VIEW OF A COMPLETE SET.

THE TUTTHILL WATER WHEEL AND GOVERNOR.



CIRCUIT CONNECTIONS OF THE EXCITER PANELS.

DRAWING TWO.

sulting in the lowering of the speed of the water wheel set, the valve *J* will drop proportionately, which will reduce the hydraulic pressure in the pipe *M* by affording a more free outlet, and the piston head *E* will descend by gravity, thus opening up more water on the wheels.

A more simple governing mechanism than that described would be hard to conceive, and it is very sensitive, in explanation of which the inventor states that it operates on a relaying principle quite as effectually as do the best of other governors of more familiar and more complicated form. Wherein the relaying exists may be hard to see, and perhaps some will dispute its presence at all, but certain it is that the hydraulic pressure from the pump is one that is delivered with mechanical precision according to the speed of the main shaft, and that the motion of the throttling valve *J* must, because of its intermediate method of actuation, lag behind any fluctuations that may occur in the hydraulic pressure by an interval of time. This situation expresses the principle which underlays all relay governors, and the Tutthill governor appears to embody it because the rate of delivery of the pump is in exact ratio to its speed, coupled with the fact that the mechanism of the governor head, though very sensitive, is sluggish in comparison with the pump.

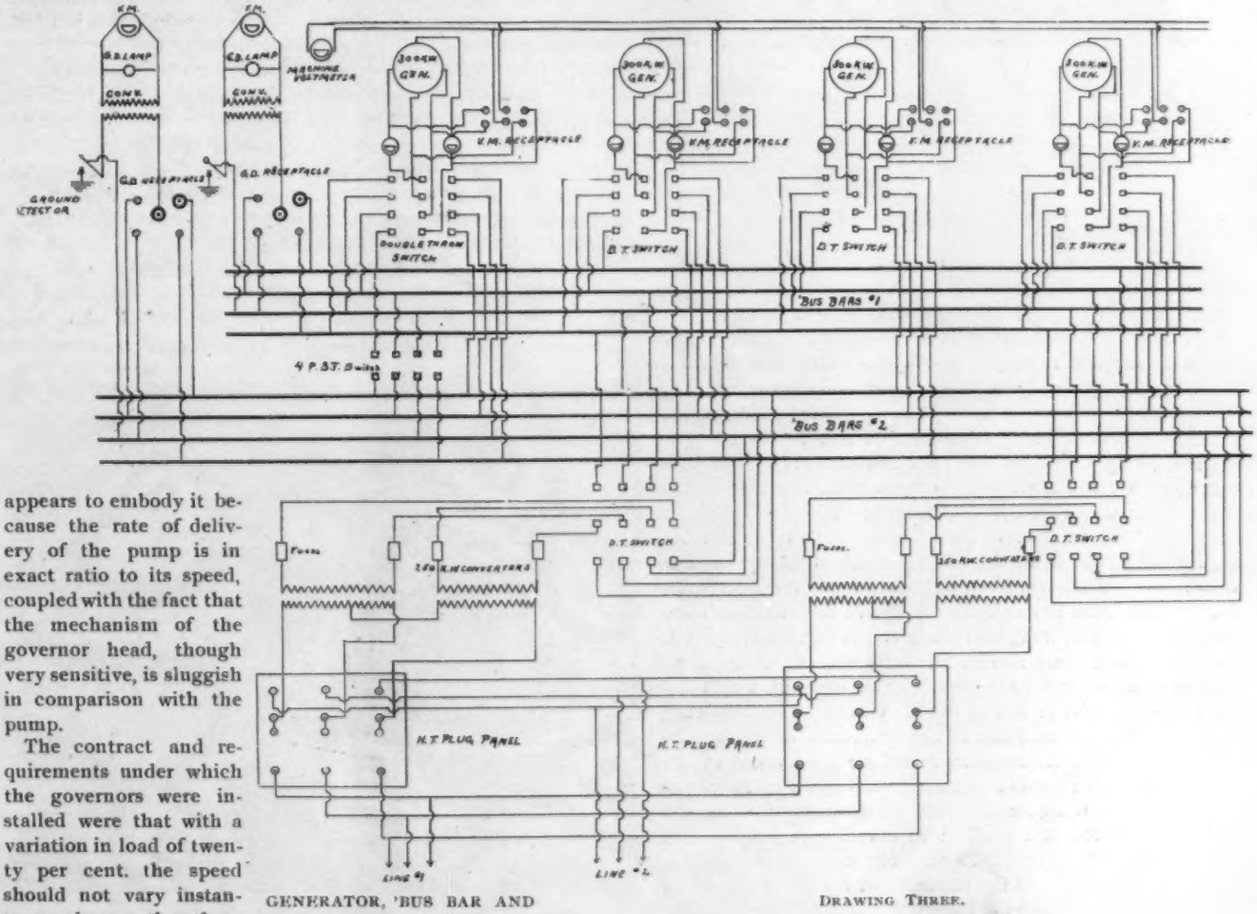
The contract and requirements under which the governors were installed were that with a variation in load of twenty per cent. the speed should not vary instantaneously more than three per cent. from normal. How closely the governors fulfilled this exaction is shown in the following extract from the letter of acceptance given by the San Gabriel Electric Company, and which gives the following as the result of the tests made of the Tutthill water wheel governors:

Upon half load of 250 amperes upon one phase of the machine, the load having been dead load resistance, with a variation of twenty amperes, with speed of normal, 425 revolutions, the variation, as shown by the tachometer, was between four and five revolutions per minute.

With the same load, throwing off fifty amperes, making twenty per cent. change, the variation was between seven and eight revolutions from the normal.

Throwing the fifty amperes back on, making a variation of about twenty-five per cent., the variation of speed was practically the same as above.

With the same load, 250 amperes, throwing off ninety amperes, which is a little more than 33⅓ per cent. change, the variation in the speed was fifteen revolutions above and five below, and the speed came back to normal without racing; throwing on ninety amperes, the variation in speed was practically the same.



GENERATOR, 'BUS BAR AND TRANSFORMER CIRCUITS.

DRAWING THREE.

THE FOURTH GENERATOR IS NOT SHOWN HERE.

INTERIOR OF THE SAN GABRIEL POWER HOUSE.

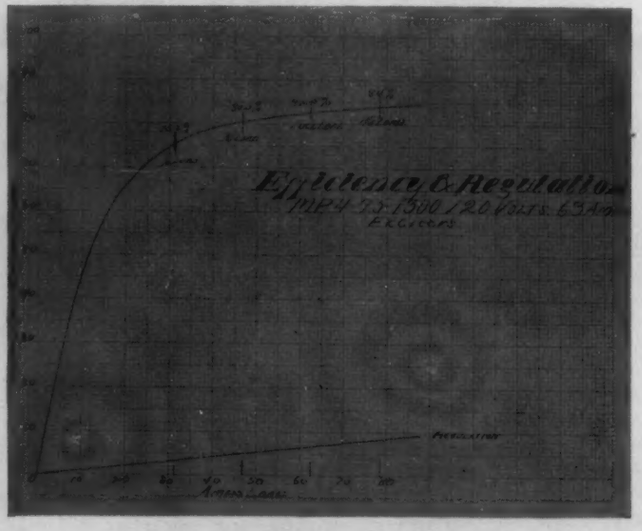
A flexible connection between each water wheel and generator is obtained by means of two discs placed close together in parallel planes on the abutting ends of the generator and wheel shafts. Each of these discs has four pins projecting and a pin of each disc is connected to the corresponding pin of the opposite disc by means of oblong links of leather. This is an improvement over the old coupling of this type in that it uses the leather edgewise without cutting, rather than wrapped around flat as formerly. All of the electrical equipment of the entire plant is of Westinghouse manufacture, and in the Azusa station are installed four generators, but three of which are shown in the interior view given on this page. These are of the revolving armature type with overhanging collector; their output is in two-phase current at an electromotive force of from 500 to 550 volts, and their normal speed is 450 revolutions per minute. They are erected on concrete foundations, capped by wooden frames, and in order to insure accuracy of alignment and to make slight changes more easy, a sheet of boiler plate, one-quarter of an inch thick was placed on top of each wooden frame. This obviates the old trouble in the erection of direct-connected machines from cutting into the wood while the alignment was being perfected. The bearings are of the usual self-oiling type with large oil reservoirs. The armatures are entirely bar wound and the coils are held in place with fiber wedges so that no band wires are required. As a result the armatures remain perfectly reliable under most trying treatment, as was exemplified by an incident which occurred in the shipment of one of them. Owing to the breaking down of the supports under one of the armatures in the box in which it was shipped, the armature rested on the bottom of the box for a considerable portion of its trip, during which the armature made at least three complete revolutions in the box, as was shown by the position of the oil cloth covering it. In spite of these revolutions and its long ride while resting on its surface, the armature was not injured in the least except for the paint and a few turns of the cord which bind down the tape at the end of the insulation. Half a day's work restored the armature to perfect condition.

GENERATORS, EXCITERS, WIRING.

The subject of directly connecting the exciters to water wheels versus belting to the generators, was taken up by the engineers and it was decided to belt the exciters to the generator couplings. For this a crown face was put on one side of the coupling and the exciters were belted directly from it. There was some objection to belting the exciters to the generators, as the variation in voltage was multiplied when a variation in speed occurred,* but, on the other hand, a fear that the small nozzles operating the water wheels that separately drive exciters at high head would become plugged by small objects that might come down the pipe line, led to the adoption of belt-driving the exciters from the generator shafts. Regardless of this however, the engineers of the company feel that the subject is still open for discussion. The exciters are of the four-pole type, having a capacity of seven and one-half kilowatts each, which is sufficient for two generators, and delivering 125 volts at 1300 revolutions per minute.

All of the station wiring is placed in subways made of redwood boards and painted with P. & B. paint on all sides. The wiring is done with rubber covered wire on porcelain knobs, and all work is open for inspection and changes as the subways are covered entirely with removable boards. This presents no difficulty, as the cement floor of the building is made flush with the tops of these boards and thus the even floor is not interrupted. The space back of the switchboards, which are placed five feet from the

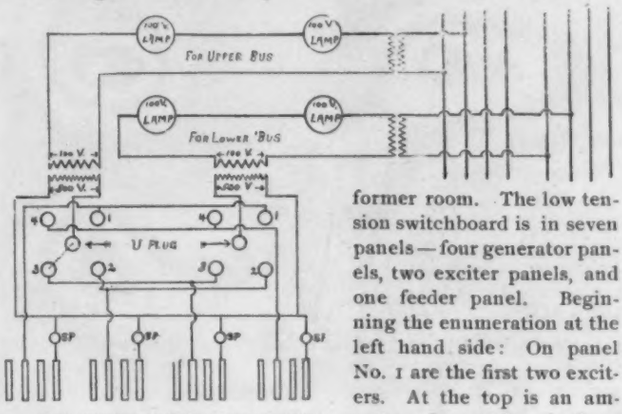
*See THE JOURNAL OF ELECTRICITY, volume VI, page 74.



THE EXCITER EFFICIENCY AND REGULATION CURVES.

wall, is made into a continuous subway, thus giving plenty of room for the wiring that necessarily becomes multiplied in the neighborhood of the switchboards. By leaving the entire space back of the switchboard for wiring and making the subway two feet deep at this point, it was found very easy to install all of the wires, and still keep them open and free for inspection.

There are two switchboards in the power house, viz.: the low tension board running along the center of the generator room, and the high tension board placed in the rear end of the transformer room. The low tension switchboard is in seven panels — four generator panels, two exciter panels, and one feeder panel. Beginning the enumeration at the left hand side: On panel No. 1 are the first two exciters. At the top is an ammeter for each of these exciters, below which is a Weston voltmeter which may be plugged from either exciter. Then follows a rheostat and a plug switch for each exciter as well as a set of three-pole, double-throw switches, by means of which either exciter may be thrown on to either set of exciter 'bus bars. There are five 'bus bars in the two sets, the sixth bar being dropped by reason of the use of one of the bars as common to both sets.



THE SYNCHRONIZING CONNECTIONS.

THE STATION SWITCHBOARDS

Drawing Two details the circuit connections of the two exciter panels, and it shows very clearly how any generator or group of generators may be excited from any exciter or combination of exciters. The rheostats in the circuit leading to the generator fields are placed near the wall in the space back of the switchboard and their leads are brought to the switchboard where they are connected to a face plate having handles extending to the front of the board. These rheostats consist of coils of iron ribbon, the turns of which are insulated from each other by mica, as is more commonly used in street railway practice. An interesting feature, and one which requires careful attention on the part of the switchboard attendant, must be noted in stations where exciters run in parallel and generators operate on two separate 'bus bars as is done at Azusa. To operate this combination so that it will be successful at all times, necessitates that the generator and its exciter shall be kept on the same set of 'bus bars. If this is not done, the exciter of one machine will run the exciter of a machine which is running on another set of 'bus bars, as a motor, by a sudden slowing down of the latter generator, thus overloading both exciters.

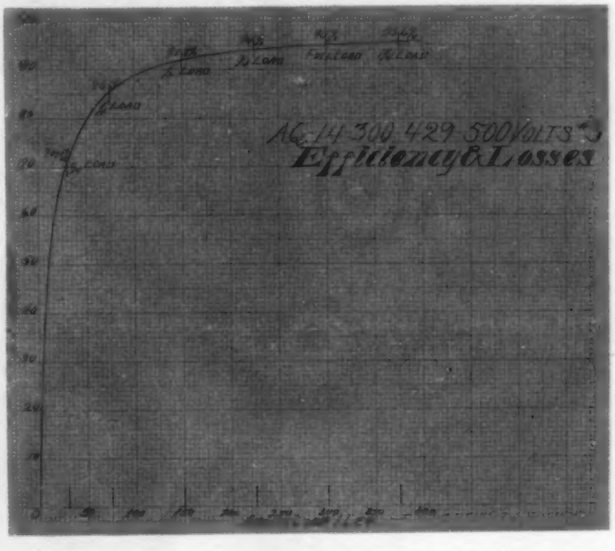
The next four panels in the low tension switchboard are for the respective generators, and each panel carries two 0 to 450 ampere ammeters — one for each phase; two synchronizing lamps, one field rheostat, one six-point voltmeter receptacle or plug switch, one four-pole, double-throw, two-phase generator switch, one five-point synchronizing switch, and a synchronizing plug. The connections of these devices are all shown in the upper portion of Drawing Three. There is but one plug for the voltmeter receptacles of the four panels, the use of which, with a common machine voltmeter, obviates any possibility of short circuit in plugging in an instrument. The generators are on the centers of the two-phase, double-throw switches, the manipulation of which will, therefore, throw the generator on either set of 'bus bars. In addition, the two sets of 'bus bars may be thrown in parallel by means of the four-pole, single-throw switch indicated, this 'bus bar multiple switch being installed on the back of the main board.

Panel 7 is the transformer or feeder panel, carrying two four-pole, double-throw switches by means of which either set of raising transformers may be thrown on either set of 'bus bars. The transformer primaries are on the centers of these switches and each of the primaries is fused. In addition, the feeder panel carries the 'bus bar voltmeters and the ground station detector receptacles, lamps and plugs shown in the upper left hand corner of Drawing Three. These two voltmeters and the machine voltmeter are the three instruments appearing on the swinging arms at the end of the switchboard.

Each generator can be synchronized with either set of 'bus bars. Incandescent lamps are used as synchronizers, the switches being closed when the lamps are at full candle power.

The high tension switchboard, located in the rear of the transformer room as stated, is of the receptacle and flexible plug type. The flexible plugs are operated with bayonet handles, which can be inserted in the plugs with a half turn, and a single pair of handles are used to operate the whole board. It is stated that these plug switches will easily open any short circuit on 15,000 volts, or any inductive load, as it is only necessary in case of heavy arcing to remove the plugs to a greater distance. How these switches are connected to the transformers and lines is shown at the bottom of Drawing Three. With the transformer leads terminating at the switch centers, and with the lines connected to the upper and lower receptacles, the throwing of either set of raising transformers, either singly or in multiple, on either line becomes a simple matter. A method for coupling the lines in parallel is also provided by the use of flexible plugs on the double set of receptacles connected with the transformer leads along the center of the high tension plug panels, or the lines may be thrown in multiple direct by connecting the upper and lower rows of receptacles of a panel with flexible plugs.

The process of synchronizing alternators is one of determining the phase position of two machines that are to be coupled in multiple arc, so that when these phase positions are identical, or technically, "in synchronism," the paralleling switch may be thrown on the instant. The comparison of the value of two forces, each existing for a period of but one-fiftieth of a second, and the ability to determine the exact interval of time when these constantly varying forces coincide at every point or sphere of their brief existence, is a process as beautiful as it is wonderful to the layman. Several different methods of synchronizing polyphase generators have been described in previous issues of THE JOURNAL OF ELECTRICITY,* but the method now to be described embodies some in-

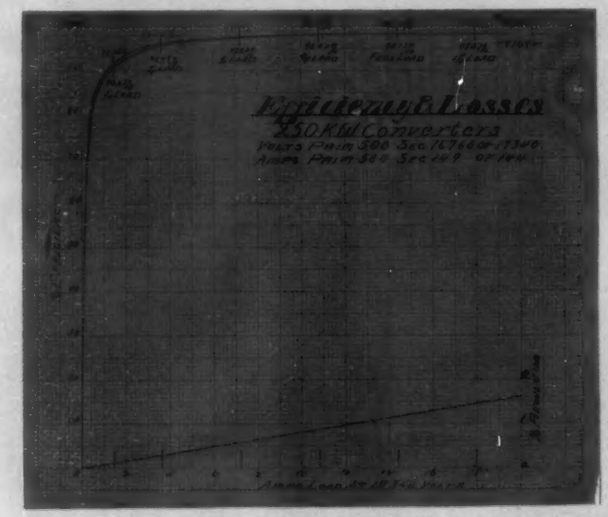


THE GENERATOR EFFICIENCY CURVE.

*Synchronizing Three-Phasers, Volume IV, page 7; Synchronizing Two-Phasers, Volume V, pages 20, 21, 70 and 71.

novations. A valuable feature of the synchronizing system used in the San Gabriel transmission rests in the fact that it may be extended for any number of generators without further installation of transformers than is required for paralleling two alternators. The diagram on page 93 gives the circuits for the synchronizing system used in both the power house and the sub-station of the San Gabriel Electric Company, in which the distinguishing characteristic, so far as the operator is concerned, is the use of a single U-plug and a single synchronizing plug. In the drawing, the four generators are represented at the bottom by the four sets of collector rings, from one of which a connection is carried through a synchronizing plug to a common 'bus wire, and from another of which (the other side of the same phase) a connection is carried to the plug receptacle whose number corresponds to the number of the generator to be synchronized. Alternate collector rings are phases on Westinghouse two-phasers, hence in the diagram rings two and four give the sides of, say, the leading phase. Each group of plug receptacles consists of as many receptacles as there are generators, plus one central receptacle, and the number of receptacle groups need not exceed one

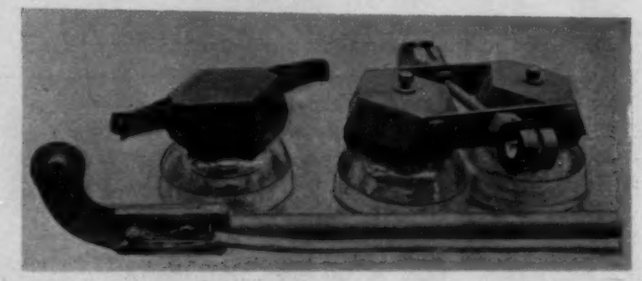
SYNCHRONIZING.



EFFICIENCY AND REGULATION CURVES OF THE 250-K. W. CONVERTERS.

for each set of main 'bus bars. Even the two groups may be reduced to a single group by connecting the terminals of a transformer to a double-pole, double-throw switch so that it may be thrown on either of the two sets of 'bus bars as desired.

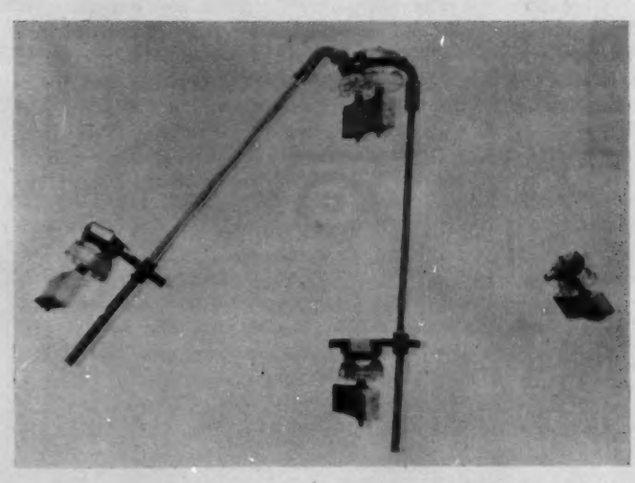
Two transformers, each having a 500-volt primary and a 100-volt secondary, have their secondaries connected in series, in which is also a series of two 100-volt incandescent lamps. The primary of one of these transformers is connected across one phase of one of the 'bus bars—the upper 'bus for instance—while the primaries of the other transformer are connected to the 'bus wire above referred to, and to the central plug receptacle, respectively. The generators are phased only with 'bus bars, and not with other generators, unless a single generator happens to be on the 'bus bar with which the first generator is to be synchronized, and as one of the primaries is always across one phase of a 'bus bar set, it is only necessary to throw the other primary across the proper phase of the generator to be synchronized. This is a process requiring two movements: first, the insertion of the synchronizing plug *S P* in the receptacle of the proper generator, (there is only one such plug receptacle on each generator panel) and, second, the insertion of the U-plug connecting the center receptacle with the receptacle corresponding to the generator to be synchronized. If, for instance, the third generator is to be synchronized with the upper 'bus bar, insert the synchronizing plug *S P* in the receptacle shown at the third set of collector rings in the diagram, which is equivalent to closing a single-pole switch; then, by means of the U-plug bridge the center receptacle of the group with receptacle No. 3, as shown by the dotted line in the drawing. The primary of the lower 500- to 100-volt transformer is now across the leading phase of generator No. 3, and a potential of 100 volts will



UNASSEMBLED PARTS OF HIGH TENSION SWITCH.

appear on its secondary. In series with this secondary, however, is the secondary of the other transformer receiving energy from the upper 'bus. Obviously, then, if these secondaries are so energized by their primary windings that their potentials oppose each other, the opposing potentials, if equal, will be neutralized and no current will flow. Any difference in potential between the secondaries will, however, create a current flow that will be in direct proportion to the algebraic sum of the two potentials; therefore, if at a given interval of time, the 'bus bar transformer has a positive potential of ninety volts, and the other transformer has a negative potential of seventy volts, the electromotive force applied to the terminals of the two lamps in series in the circuit will be twenty volts.

We are dealing now with two separate sources of electric potential, each of which start from zero, then rise to a positive potential of 100 volts, next drop back to zero, and on down to a negative potential of 100 volts, and then back again to zero, completing fifty such cycles per second, or 6000 per minute. However exact the mechanical arts may be, it is impossible to operate two generators so that they will be mechanically and electrically independent, yet put out no more or no less than 6000 alternation per



HIGH TENSION SWITCH AS ERECTED.

minute; they will vary several hundred alternations above or below the normal rate each minute, and as these variations occur they will be reflected with the utmost precision in the voltage appearing at the terminals of the two lamps wired in series with the transformer secondaries. The lamps are out at times, then they will redden and dim, then burn up brighter and dim, then perhaps they will slowly rise to full candle power, staying there for a second or two, and precisely at this instant the machine switch must

be thrown in connecting the generator to the 'bus bar, for the generators are in synchronism. A moment's delay will necessitate waiting for the cycle of full candle power to come around again, albeit the potentials will pull themselves in step even though the generators be out of phase at the time the switch is thrown. It is an inherent characteristic of polyphase machinery that it will synchronize regardless of the interval of switching-in, but synchronizing when the machines are out of phase imposes strains of mechanical and electrical natures that are always to be

THE HIGH TENSION SWITCHES.

avoided. The paralleling of the two-phase equipments of the San Gabriel transmission is a process that is as reliable and satisfactory as is the paralleling of two direct current generators, despite the fact that water-driven generators are synchronized with a steam-driven one; or that rotaries or the railroad circuit are synchronized with each other or with either one or any combination of the preceding.

All station transformers used by the San Gabriel Electric Company are of the self-cooling, or oil-insulated, air-cooled type, and, except that different numbers of leads are taken out from the different styles of transformers as they may be adapted for rendering various characters of service, they are similar in form to that illustrated in the subjoined miniature cut. The transmission proper is on the Scott system,* that is, two-phase generation, three-phase transmission, and two-phase distribution. The four 250-kilowatt raising transformers at Azusa are, therefore, two-phase three-phase transformers, and the lowering transformers at Los Angeles are three-phase two phase transformers, but the last named deliver variable electromotive forces as required, while the former are wound at a fixed ratio, approximately taking 500 volts and delivering 16,500 volts to line. In these transformers both primary and secondary are divided up into several flat coils, wound with many layers and few turns per layer, each coil being insulated separately, and it is claimed that the advantages of this construction are that it divides the total electromotive force between several coils, reducing proportionately the strain within an individual coil; that it divides the electromotive force in a single coil between many layers, thus reducing the potential between adjacent layers; that it enables the coils to be spread apart at the ends, so that a very large surface is exposed to the oil, thus providing ample radiating facilities and most thoroughly insulating the bent part of the coils; that the regulation of the transformer is greatly improved thereby; that the windings may, with great facility, be connected in series or multiple, giving a wide range in electromotive force; and that in case of damage to a coil, another one may be substituted with little trouble and without returning the converter to the factory. In this type of transformer, the core and coils are placed in iron boxes composed of two parts; an inner portion made of heavy sheet iron for containing the oil, and an outer framework of angle iron for supporting and

holding the inner case. The surface of the inner case is broken up into a number of corrugations or flutes, so that the surface exposed to the air is greatly increased and capable of dissipating into the air the heat generated in the transformer; the oil acting as a conductor for transferring the heat from the transformer to the case. The transformers are set on wooden frames, each of which is independent of the others and can easily be removed, and they are arranged so that should it become necessary to remove a transformer from the case, it can be placed on rollers and rolled out into the generator room under the crane.

The low tension leads, after passing through the subway from the feeder switchboard, rise on the inner surface of the wall between the generator room and the transformer room. Here the primary fuses are installed on separate marble slabs and the leads go through the walls to the transformers.

From the transformers, the high tension leads are carried overhead on line insulators to the high tension switchboards, choke coils and lightning arresters. The former are of the flexible plug type as previously described, and the choke coils and arresters are of the so-called "pyramidal form," owing to their arrangement in the form of an inverted pyramid as seen in Figure 1. In this diagram, each circle represents a choke coil; each rectangle represents one unit type "C" non-arcing metal lightning arrester, and the grouping is such that there are six choke coils in series with seven 2000-volt arresters between each line and ground. Figure 2 shows how this is done by the use of eighteen arresters, as at Azusa. The arresters are placed on a platform overhead in the transformer room and thus far they have worked quietly and required no attention.

ARRESTERS.

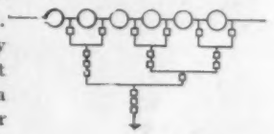


FIGURE 1.

Full details concerning the line are presented in the table of engineering data appended hereto, but the noteworthy features of it are that it is in two three-phase circuits, each consisting of three No. 5, hard drawn copper wires, supported on 5½-inch Locke glass insulators which are mounted on locust pins boiled in paraffine and then driven into cross arms previously painted with P. & B. paint. Each set of lines is spiralled — one-third turn at 7¾ miles from the Azusa end, and one-third turn at 7¾ miles from the sub-station. The two lines are spiralled in opposite directions. The line is twenty-three miles in length, the poles are round and placed about 125 feet apart. The six wires are mounted on two cross arms, four wires being on the lower arm and two on the upper, the three wires of each circuit being placed at the corners of an equilateral triangle having thirty-inch sides.

THE LINE.

The effects of spiralling were illustrated in an interesting way during the starting up of the plant. One line was, at that time, installed without spirals, and the other was installed with two one-third spirals. There seemed to be no effect from mutual induction, but the telephone line objected to this arrangement. The telephone was quiet when the current was carried on the line having the two spirals, but when the straight line carried the current, it was impossible to use the telephone. It was therefore decided to put two spirals in the straight line at the same points as the other spirals, but in the opposite direction. This was done and the telephone seemed to be satisfied. There is no noise whatever on the telephone line and the instruments and lines can be used and are used in long distance work by the Sunset company with great satisfaction.

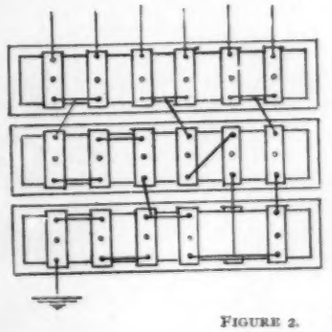


FIGURE 2.

*Volume V, page 130.

The telephone line is transposed every fifth pole and the wires are placed one above the other on the same side of the pole. The engineers of the plant hold that this arrangement has an advantage over placing the wires on two sides of the pole on a short cross arm or bracket. The telephone line is of iron wire, No. 12, and is so satisfactory that it will probably result in the discontinuance of the installation of copper telephone circuits hereafter on transmission plants of moderate length.

The sub-station, situated on the east side of Los Angeles street near Third street, is a brick structure with steel roof trusses, corrugated iron roofing and concrete floors. The transmission lines enter from the rear and are at once carried into the arresters and choke coils, whence they continue to the high tension switches illustrated on page 95. The arrester equipment is identical with that at the power house. The sub-station is a one story structure, but the high tension and transformer portion is of two stories,

These switches are erected in sets of three; each double switch is connected at the pivot end to the transformer. The lower end of the jaw on one side connects to line *A* and on the other side to line *B*; thus each set of switches is a paralleling switch for the main line, and a circuit can be changed from one line to the other, if the lines are in parallel at the generating end, without disconnecting or interrupting the service.

The fuses, which are thirty inches long, are mounted in soft rubber tubes. If the fuse blows, the current of air in the tube blows out the arc, and the falling of the rubber tube to the floor insures the breaking of the arc and at the same time marks the place where the fuse has blown. The station attendant is therefore not troubled in finding where the fuse has blown, and while there are no less than eighteen two-way switches, the operation of these is very simple. This switch is very cheap and will probably come into general use in its present or modified form.

ROTARIES AT THE RIGHT, TRANSFORMERS IN THE REAR.

LOS ANGELES SUB-STATION OF THE SAN GABRIEL ELECTRIC COMPANY.

and about seven or eight feet above its floor are the high tension fuses and switches in detail and as assembled, on pages 94 and 95. These switches, which are known as the M.-T. high tension switch, are mounted on line insulators and are composed of a long wooden jaw upon which is mounted the high tension fuse and the switch contacts. The upper end of the switch jaw is mounted with a removable socket on a pair of high tension insulators; the lower end of the switch jaw swings into a clip terminal mounted on another insulator and when the switch is closed it is in a position about forty-five degrees from the horizontal. When the switch is opened it is only necessary to pull or strike this handle with a special grounded switching stick and the switch jaw falls to a vertical position where it is caught in a bumper clip mounted on a third glass insulator. The upper or pivot end of the switch is connected to the transformer so that when three switches are open, the jaws are dead. By a simple lifting movement the jaw is unhooked at the top and if a fuse has blown it can be replaced, or an extra jaw, of which several are supplied, can be put in its place. A high tension fuse, or a set of three high tension fuses can be renewed in about one minute, and this can be done without any danger to the station attendant.

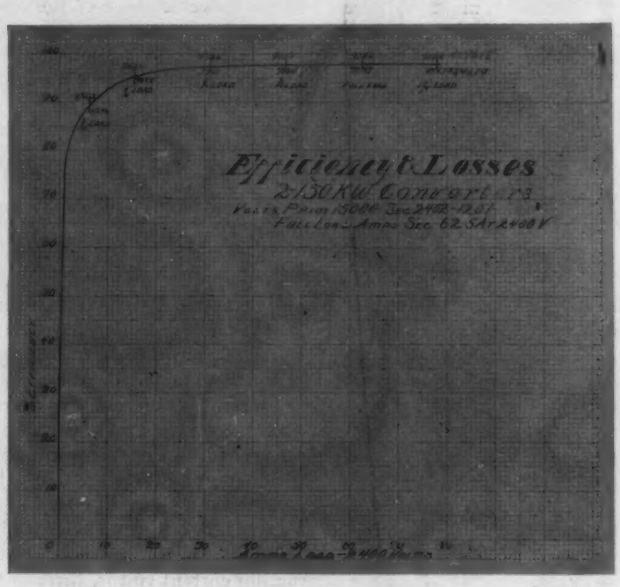
HIGH TENSION SWITCHES.

The lightning arresters are of the same type as those at the generating station.

The transformers are set in pairs in the room immediately under the high tension room, and each pair reduces the three-phase line current at 15,000 volts to two-phase current of the voltage required for its particular service. Each transformer is set on a separate wooden base and the floor is arranged with sub-ways so that all of the low tension wiring is below the floor. The large "I" beams of the high tension room floor are of sufficient width and size so that a timber which is cut in between the webs of these can be used as a support when lifting a transformer out of the case. The high tension wires of the transformer to be lifted out are, of course, dead during this operation, and the wires leading to the room above are so arranged that the men need not be injured by proximity of high tension wires, if ordinary care is taken. The low tension wiring is done here, as at the generating station, with rubber covered wire on porcelain knobs. Each pair of transformers, or system of transformers, is equipped with spark gap protectors tapped in at the center of its low tension side, and thus static sparks from the main line are kept from interfering with the convenience and comfort of customers.

The various characters of service rendered by the San Gabriel

company made it advisable that the lowering transformers should deliver radically different electromotive forces having nominal values that are but approximations. Thus, the two 150-kilowatt transformers supplying the 500-direct-volt rotary are wound for the secondary delivery of either 370, 400, 440 or 460 volts. Then there are four 125-kilowatt transformers delivering, nominally, 218

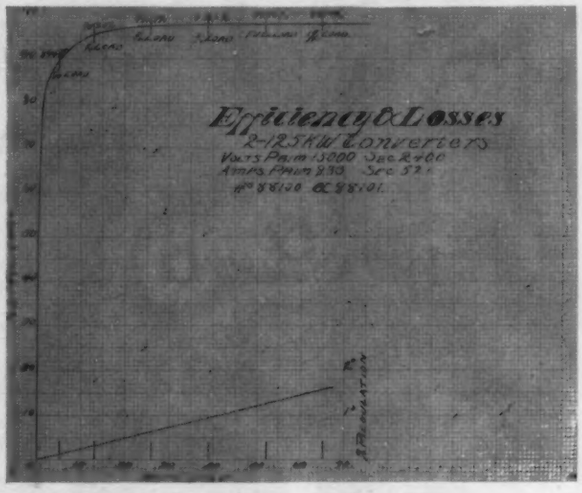


EFFICIENCY CURVE FOR THE TWO 150-KILOWATT CONVERTERS.

volts; four 150-kilowatt transformers delivering 2400 volts, besides the two 125-kilowatt lowering transformers delivering a very wide range of electromotive forces to the regulating dials and reverse switches, and the series transformers whose primaries take current from the regulators just mentioned and whose secondaries are cut into the four legs of the two-phase circuits leading to the 250-direct-current-volt rotaries. The above, together with two 250-kilowatt transformers delivering 218 volts which are now being installed, constitute the transformer equipment of the sub-station.

THE DISTRIBUTION.

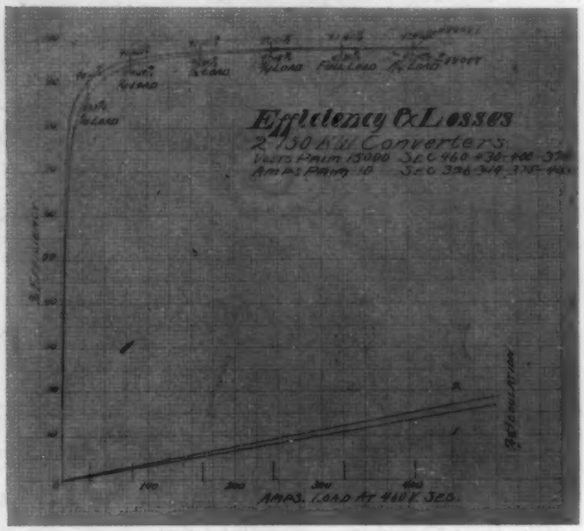
The sub-station was installed so as to enable the operation of four varieties of electric service, viz.; (1) a single-phase 2400-volt



CURVES FOR CONVERTERS DELIVERING 2400-VOLT, TWO-PHASE CURRENT.

lighting system for residence and outlying districts; (2) a 2400-volt two-phase power service for synchronous and induction motors; (3) a 500-volt direct-current power service for direct-current motors, elevators, etc., and (4) a 220-volt direct-current three-wire service for incandescent and constant potential arc lighting on either the 110- or 220-volt system. The 2400-volt single-phase lighting circuits are, of course, merely one side or the other of the two-phase 2400-volt power system, as the delivery of both incandescent lighting and power from the same transformers are not attended with difficulty. The 500-volt power service was made necessary by the large number of 500-volt direct-current motors in use in Los Angeles prior to the installation of the San Gabriel plant, and the 220-volt three-wire system was preferred by the San Gabriel company's engineers to a low tension alternate-current distribution because direct currents enable a more satisfactory operation of constant potential arc lamps, and, above all, their power factor is at all times 100 per cent., while against them can only be charged the fact that the efficiency of the rotary converter is slightly lower than the efficiency of the stationary transformers.

The operation of the 2400-volt lighting circuit requires no specific reference beyond the fact that the single-phase current



CURVES FOR TRANSFORMERS OPERATING THE 500-VOLT ROTARY.

is distributed through Stilwell regulators giving a range of from 2200 to 2400 volts.

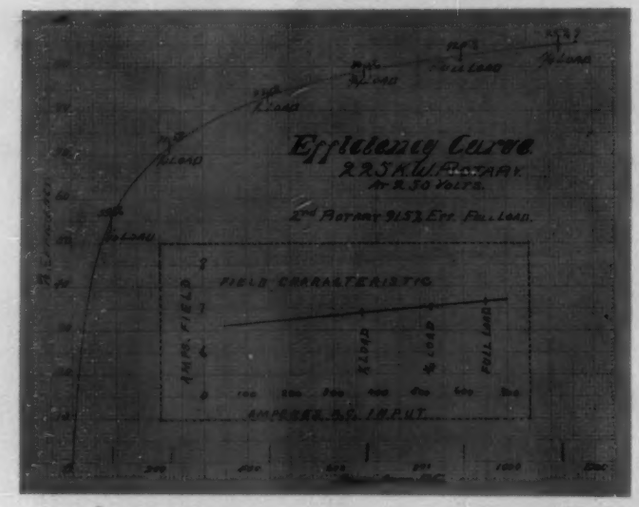
On the two-phase power circuit are several large type "C" induction motors, here illustrated, and among the larger consumers are the Globe Mills, of the McDonald Feed and Milling Company, which is operating a 100 horse-power motor and a 40 horse-power motor directly from the 2400-volt lines at a distance of one mile from the sub-station. The City Brick Company, three miles away, is operating a 40 horse-power motor with transformers at 400 volts. The Bradley Fertilizing Company, six miles distant in another direction, is operating 75 horse-power—a 50 horse-power, 20 horse-power and 7 ½ horse-power motors. The Globe Mills are new mills which have been worked to a capacity of 266 barrels per day, although they were guaranteed for but 200 barrels, and as the mill works close to the higher rate, the starting of them by an induction motor was considered as presenting great difficulties, since it was necessary to start at full load of the 100 horse-power motor, and the starting torque is said to be once and a half times full load torque. The machinery is divided into two portions, part being operated by the 40 horse-power motor and the remainder by the 100 horse-power motor, and the writer can bear witness to the fact that these motors take up their given loads with surprising ease and celerity.

Before proceeding to the direct-current distributions, and as the use of rotary converters is not common in California transmissions (although many will be in operation before the close of the com-

ing year), a brief reference to their principles of operation may be of interest. A rotary converter transforms alternating to direct current, or *vice versa*, by reason of its process of rotation as a synchronous motor. It is simply a commutating machine which makes alternating and direct currents interchangeable, just as primary and secondary potentials become interchangeable in ordinary transformer work. Its mechanical design and construction is similar to direct-current multipolar generators.

ON ROTARY CONVERTERS.

The field poles of the rotaries in the San Gabriel plant are laminated and rigidly held by a circular frame of cast iron; the armature, or revolving element, is of the iron clad type with core built up of thin steel plates of the best magnetic quality and containing bar copper windings; the commutator and winding are practically identical with those of a direct-current generator of equal capac-



EFFICIENCY AND EXCITATION CURVES OF TWO 225-KILOWATT ROTARIES.

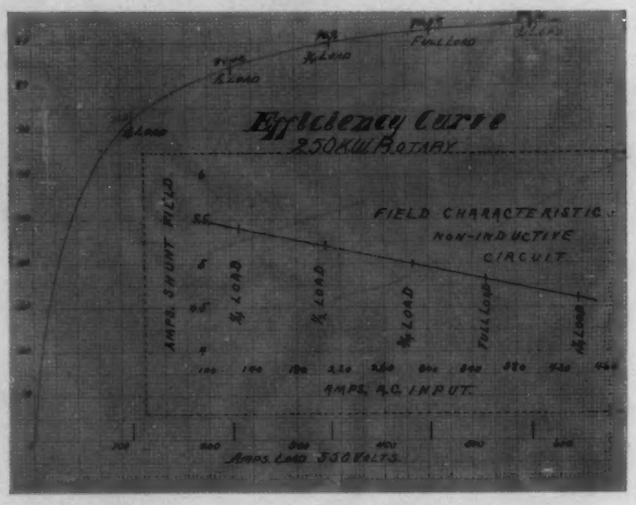
ity, but the shaft carries, in addition to the commutator, four collector rings similar to those used on a two-phase generator. The armature winding is tapped so that the terminals of the two sets of two-phase leads are taken from points on the winding 90 degrees apart, and these leads go to their respective collector rings. Two-phase current is applied to the collector rings and the machine run as a synchronous motor from which direct current may be taken through brushes and the commutator; or, to reverse the operation, as has been frequently done in the San Gabriel plant, direct-current may be applied to the commutator, when the machine will run as a direct-current motor and deliver two-phase alternating-current at the collector rings.

One marked difference exists between the rotary converter or transformer and the ordinary alternating-current transformer. In the latter, the relation between the primary and secondary potentials is fixed by the ratio existing between their respective windings; in the rotary transformer the potential of the direct-current side, be it delivered or impressed, is invariably higher than the potential of the alternating side for the reason that while the crest of the potential wave in alternating current work coincides in value with the electromotive force obtainable from the same machine when used as a direct current generator, the effective value of the alternating potential wave is its mean effective voltage—not its maximum or crest voltage. Other conditions, such as form of wave and the number of phases, exert further influences upon the relation existing between the voltages at the alternating and direct current sides of a rotary converter; but this relation, if the generator be given a true sine wave, will be about seven-tenths times the corresponding continuous-current voltage in a two-phase rotary, and about six-tenths times the corresponding direct-current voltage in a three-phase rotary.

In no case, therefore, can the ratio of transformation in a rotary converter be arbitrarily fixed as is so readily done with alternating-current transformers. It is impossible to wind a rotary transformer in a ratio of, for instance, 10 to 1, so that a potential of 2400 volts may be applied to the collector rings and 240 volts in direct-current will be available from the commutator. To get 240 volts direct-current, an alternating potential of 173 volts in two-phase current must be delivered to the collector rings of the San Gabriel rotaries, hence step-down transformers must be installed to reduce the line potential of approximately 15,000 volts to the 173 volts required to produce 240 volts at the direct-current end. As step-down transformers may be readily arranged to deliver a variable voltage through different terminals, the delivery of different direct-current voltages from the rotary becomes only a matter of connecting the proper set of transformer terminals to the collector rings. Secondary regulation is effected by the potential regulator, to be more fully described hereinafter.

Returning to the direct-current distributions, the 500-volt power circuit is taken from a 250-kilowatt compound wound rotary which is supplied with two-phase current, at nominally 380 volts, from two 150-kilowatt transformers. Four secondary leads, of 270, 400, 440 and 460 volts respectively, are brought out of these transformers so that any necessary voltage may be obtained on the direct current side of the rotary. Direct-current is taken off by twelve sets of carbon brushes, with two brushes on the arm of each set; the brush holders are of the swivel type; the armatures are bar wound; the cores have cooling air ducts, and there are four collector rings on the alternating-current end, while overhanging as an extension of the main shaft is a 10 horse-power induction starting motor. Starting from the alternating current end is, therefore, a process of driving the rotary as a direct-current generator by the starting motor and thereby exciting the fields, which, in the 225-kilowatt rotaries, are simply shunt wound. When the rotary is up to synchronism, the two-phase current may be thrown on and the rotary will always be of right polarity. This is a marked advantage over rotaries that are self-starting from the alternating-current end. While the San Gabriel rotaries may be started from either side, they are ordinarily started on the direct-current side, that is, one from the other by means of a water rheostat, in fact, a start can be made from the direct-current side of any rotary with much less fluctuation than from the alternating-

DIRECT CURRENT SERVICE.



EFFICIENCY AND EXCITATION CURVES OF THE 250-KILOWATT ROTARY.

current end, since the starting current can be applied very slowly, giving the governors at the power station ample time to act.

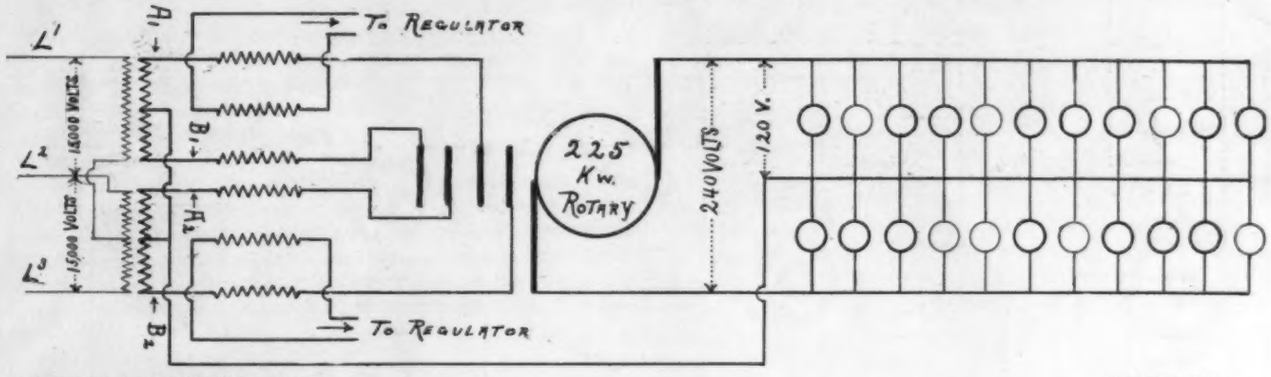
All incandescent lighting is delivered from these rotaries on the Lamme system of electrical distrbiution*, which is the equivalent of the Edison three-wire system in that the circuits are of three

* United States Letters Patent. 607,621 issued July 19, 1898.

conductors—a positive, a negative and a neutral. The rotaries deliver from 220 to 240 volts in direct-current to the outside wires of the three-wire system according to the load, while the neutral is carried back to the reducing transformers where it taps in to the middle point of the secondaries of the two-phase transformers from which the rotary is operated. This is shown in simplified form in Drawing Four, and it is interesting to note that while in regular practice the neutral is tapped in to the secondary of each transformer, the system will operate almost equally well should either one of these connections be dropped.

The regulation of this three-wire service is effected in the manner shown in Drawing Four, wherein the two secondaries of a series transformer are introduced into the respective sides of each of the two-phase circuits operating the rotary. The four wires constituting the two-phase circuit are lettered A_1 B_1 A_2 B_2 respectively, and each includes one of the two secondaries of the two series transformers shown, the primaries thereof being supplied at various electromotive forces by two regulating dials that commutate loops from the secondary windings of two 125-kilowatt lowering transformers. The dial points are in circular form and the collecting arm is actuated by a hand lever through a ratchet motion. By giving this hand lever a quarter twist the direction of motion of the arm is reversed. When the arm comes to the end of its travel, giving no electromotive force to the series transformers, an automatic interlocking device releases the reversing switch which allows the action of the regulator to be made to raise or lower the electromotive forces of the rotary. The range of the regulating dial is from 220 to 320 volts on the direct-current side, while without the regulators the rotary delivers about 270 volts, giving a range of 50 volts above and below normal. This is obtained in 68 points of less than 2 volts each.

REGULATION.



SIMPLIFIED DIAGRAM OF THE DIRECT CURRENT DISTRIBUTION.

DRAWING FOUR.

The auxiliary plant, which adjoins the sub-station, consists of 500 horse-power in water tube boilers burning oil, a 500 horse-power Corliss non-condensing engine and a 300-kilowatt, 2400-volt, two-phase generator driven therefrom by independent ropes. The exciter is mounted on a bed plate directly connected with the generator frame and is belt driven from the end of the generator shaft. This generator, during periods of low water, operates the 2400-volt circuit previously referred to and also supplies its surplus current to the two-phase sides of the four 150-kilowatt lowering transformers, which then deliver three-phase current to the line at an electromotive force of about 15,000 volts, thus working in parallel with the power house at Azusa.

The combinations existing in the sub-station are presented in simplified form in Drawing Five, the fundamental feature of which is the fact that every variety of service delivered may be transformed from the line potential, or, conversely, either the steam-driven generator or the 500-volt rotary (if driven from the direct-current side) may deliver three-phase current to the line, thereby assisting the Azusa plant or operating the entire service should the transmission be disabled. During the peak of the load the 500-volt rotary has been so operated from the Los Angeles Railway plant, which in addition has also carried the 500-volt power circuit of the San Gabriel company, and this expedient has enabled the San Gabriel company to maintain uninterrupted service during the dryest summer that California has ever known.

No better way exists of conveying an understanding of the different combinations under which the electrical equipments of the plant have been worked during the trying season of drought just passed than by recalling the fact that the system may be resolved into five distinct portions, viz: (1) The Azusa station; (2) the Los Angeles auxiliary plant; (3) the practically unlimited power at 500 volts from the plant of the Los Angeles Railway Company; (4) the 500-volt rotary, and (5) the 250-volt rotaries. From the three first named sources of power, the four different characters of service heretofore enumerated must be rendered. Last summer the Azusa plant was capable of delivering but about one-third of its capacity to the line, and when it is known that within a month after the plant was started it was called upon to carry a greater load than was believed it would be possible to secure within six months, it will be seen that it was necessary to take heroic action to meet the exigencies thrown upon the plant by reason of the shortage of water and the unlooked for increase in business. The auxiliary plant was therefore installed early in the summer in the belief that it would carry the 2400-volt service, and that the Azusa plant could, with the assistance that it would receive from the auxiliary plant, carry the direct current lighting and power loads. It soon transpired, however, that these two plants were unable to carry the load, being short 250 kilowatts, practically all of which would have to be delivered to the three-wire mains at 220 volts. The only available source of power from which this 250 kilowatts or more of energy could be drawn was from the Los Angeles railway plant and the reinforcing of the transmission line thereby through the operation of the 500-volt rotary from the direct current side.

As might be presumed, the varying character of the load, as the novel nature of the installation, brought about many interesting and instructive combinations, among which may be enumerated the following, each of which has been made and tested under actual working conditions in commercial service. At all times the four classes of service have been delivered without interruption: First is the ordinary combination of running the entire plant from Azusa, in which the generators, as well as the 250-volt rotaries were run either singly or in multiple; second was the running of the entire system from the steam plant; third, the running of the entire system from the railway plant through the 500-volt rotary; fourth, the operation of any or all of these sources of power either singly or in multiple; fifth, the running of the 225-kilowatt rotaries in multiple from the alternating current side, and in series on direct-current sides, in which event one rotary delivers 220-volt service, and the two being in series operate the 500-volt power circuit; and sixth, the operation of the two 225-kilowatt rotaries in series from the railway plant, one

rotary operating one-half the three-wire system direct at 220 volts and the other rotary operating at 220 volts in series with the other half of the three-wire load. This last combination is the most remarkable because of the first rotary, operating one-half of the three-wire load direct at 220 volts, is driven by the alternating-current output of the rotary which has 280 volts on the direct current side. The auxiliary plant has also run in multiple with the two 225-kilowatt rotaries in series. As to the two 225-kilowatt rotaries, one has been run as a single-phase rotary, furnishing 220 volts and 70 per cent. of the total capacity of the machine. These two rotaries have been run in multiple, using one as a two-phase and the other as a single-phase machine, and in no instance has the polarity been reversed.

The means by which these combinations and others may be effected will be seen from Drawings Five and Six, but the running of the rotaries in series from the direct-current ends and the operating of the three-wire service therefrom presents features of such unusual interest that a more extended reference is deemed advisable. Assume that, as in Figure 3, an alternator is delivering 100 amperes at 500 volts to the load as shown. If this coil is in two equal sections, *A B*, the electromotive force across the terminals of each will be 250 volts, and if the terminals of section *B* are connected through the load *L L*, a current of 200 amperes at 250 volts will be found in the circuit so formed. How is it then, that a current of 200 amperes may be shunted from a coil of wire that carries but 100 amperes? Such a situation is impossible in direct-current practice, but it is perfectly rational in the present instance. As load is thrown across the terminals of section *B*, an equal load arises in section *A*, being in series with *B*, but the energy thus formed in *A* must be expended, so it is converted into magnetic lines of force that appear in the iron bar, which, in turn, must shift the energy so derived into whatever receptive device may be present. Thus it is that the magnetism of the bar is transformed into electric current in the wire of section *B*, which, assuming that there are no losses in conversion, will deliver 100 amperes at 250 volts to the load *L L*. One-half of the load, or 25 kilowatts, thus represents the energy absorbed in section *A* and reappearing in section *B*; the remaining half of the load is taken direct from the main circuit because of the counter electromotive force of the windings of section *B*. Sections *A* and *B* are, therefore, linked together magnetically so that they work as if coupled in parallel for the operation of the load *L L*. In this diagram is found the principle of the auto-converter. Advancing now to the combination in which two rotaries are operated in series from the railway plant, it will be seen that the combination is an exact counterpart of that just given. In Figure 4, the 500-volt generator is delivering 100 amperes to two 250-volt rotaries in series, one of which is connected on its direct-current side to the lighting load of 200 amperes at 250 volts. The alternating-current sides of these rotaries are linked together through raising transformers in which the secondaries are in parallel at 15,000 volts. The path taken by the current as it leaves the generator is indicated by arrows, 100 amperes going first through the direct-current side of the rotary *A* whence it continues, shunting rotary *B*, to the lighting load *L L*, through which it passes, and returning thence to the generator. A current of 100 amperes at 250 volts, or 25 kilowatts, is thus taken from the main circuit and applied to the load direct; but the remaining 25 kilowatts centers in rotary *A*, which, being unable to absorb it as might be done with a rheostat, for instance, delivers it to the two-phase side, whence it continues on through the raising and lowering transformers to the alternating-current side of rotary *B*, This rotary takes the alternating-current and delivers a direct-current of 100 amperes at 250 volts to the load, less losses. Rotary *B* is thus driven electrically from rotary *A* as effectually as though they were mounted on a common shaft. In fact the combination which exists is the same as though it be assumed that *A* is a 25-kilowatt motor in series with one-half of the load *L*, and that the motor

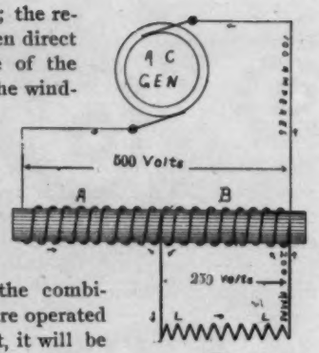
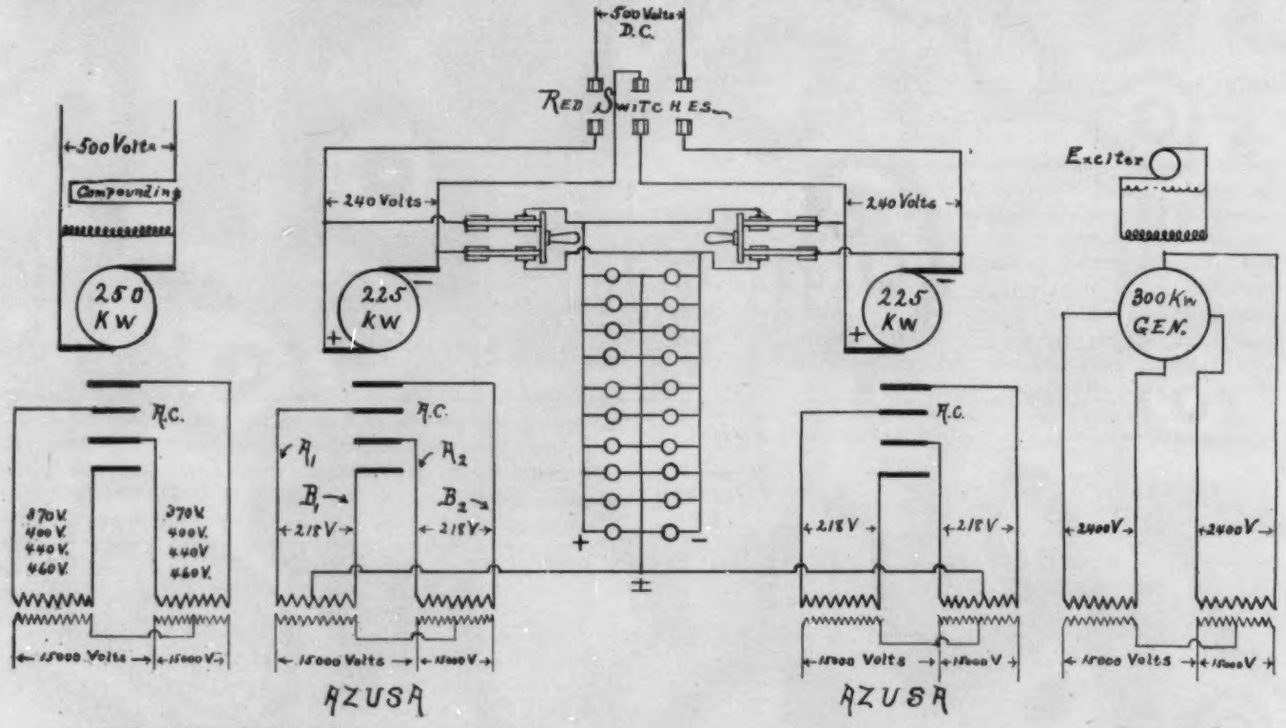


FIGURE 3.



SIMPLIFIED DIAGRAM OF THE LOS ANGELES STATION CONNECTIONS.

DRAWING FIVE.

SOME INTERESTING COMBINATIONS.

A operates the generator *B*, which delivers 25 kilowatts for operating the other half of the load *L*. In actual practice the rotary *A* is operated at 280 volts, while the rotary *B* is operated at 220 volts, and the higher electromotive force of rotary *A* enables it to drive rotary *B*—the proper variations in the electromotive force being obtained by the manipulation of the regulator dials. The rotaries are coupled in series by means of the "red handle" switches appearing in Drawings Five and Six.

It is evident that the plant is so arranged that it can be operated under several advantageous conditions; for instance, the first advantage was gained from the 500-volt rotary. The electrical end of the transmission plant was ready for operation before the water could be turned in and each day that could be saved on the installation was considered a great advantage. The railroad current at 500 volts was, therefore, run into the sub-station and the 500-volt rotary was used as a direct-current-alternating-current rotary, giving alternating-current which was used for getting the whole plant in operation. The other rotaries were started with this current; all the transformers were dried out and properly filled, etc.; all of the bearings were tested and put in proper condition for operation; all electrical connections completed, synchronizers adjusted and instruments tested, and everything was ready for operation, both at the sub-station and at the generating station, before the water was turned on. This saved about one week's time in starting the plant.

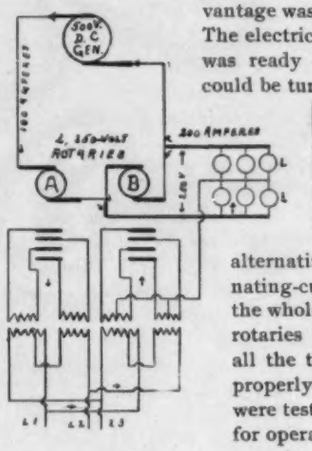


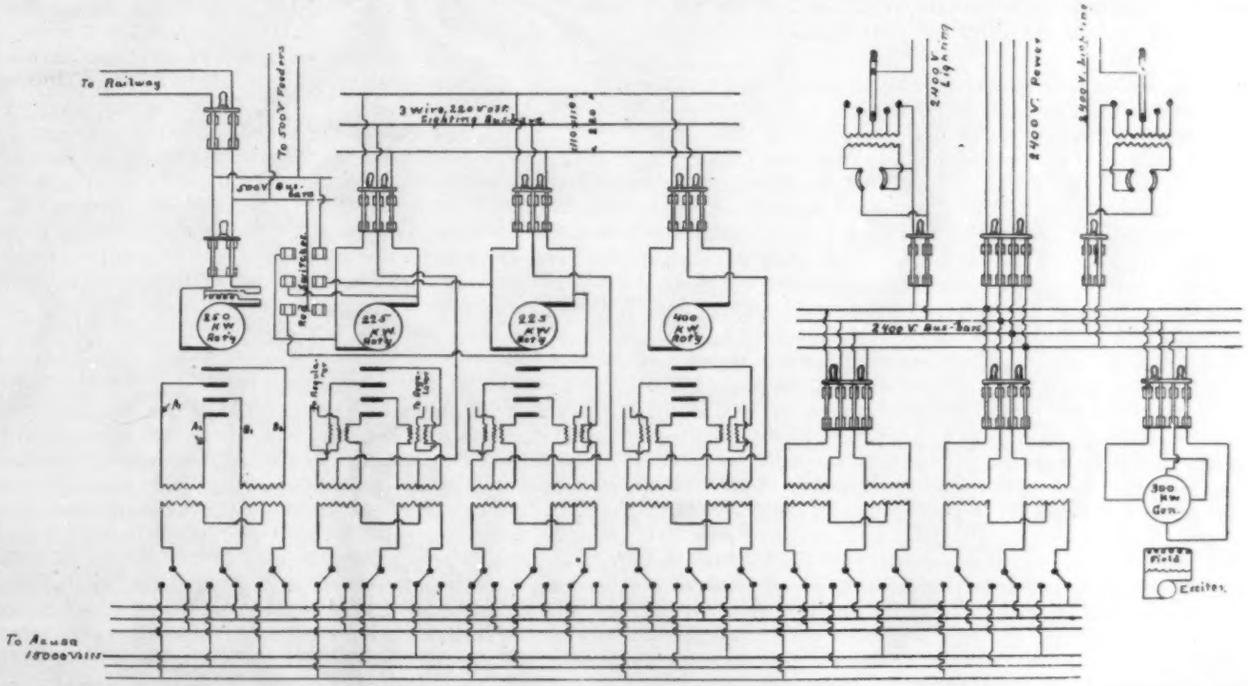
FIGURE 4.

The conditions under which the plant is now operating are equally interesting. The entire day load is carried by the Azusa and auxiliary plants working in parallel; the San Gabriel company has taken over the 500-volt power or commercial motor load of the Los Angeles Railway Company, on which is a direct-current motor driving two Edison generators feeding into the underground mains of the Los Angeles Edison company, which is part of the system of the Southern California Power Company, a competitor of the San Gabriel company; during the peak of the load the 500-volt rotary takes current from the railway plant, stepping it up to 15,000 volts, at which electromotive force it is thrown in parallel with the Azusa and auxiliary plants, and, finally, the main generators of the Los Angeles Edison system are driven by steam and work in parallel with the motor-driven generators just referred to. During the peak of the load, therefore, five different stations are electrically tied together for the delivery of incandescent service, viz: The Azusa water-power plant, the auxiliary steam plant, the San Gabriel sub-station, the Los Angeles railway plant, and the Los Angeles Edison station. In other words, four stations, which are entirely dissimilar in that they deliver 15,000-volt three-phase current, 2400-volt two-phase current, 500-volt direct-durrent, and 220-volt direct-current respectively, are all coupled together in parallel for the operation of two entirely different and independent systems of three-wire direct-current distribution.

The many combinations and varieties of service rendered have necessitated the installation of switchboards of more than ordinary interest. They are divided into five different classes, to-wit: the high tension boards and switches previously described, the alternating-current distributing panels for 2400-volt power and lighting, the rotary converter panels, the 500-volt distributing panels, the three-wire distributing panels, and the panels for the control of the auxiliary steam plant.

SUB-STATION SWITCH-BOARDS.

The 2400-volt systems, including the auxiliary plant, are handled from the same switchboard (that at the left in the rear of the sub-station in view on page 96) although independently controlled from separate panels. Beginning from the left, Panel 1 is the exciter and transformer panel, and carries one 100-ampere ammeter; one 150-volt voltmeter; two synchronizing lamps and plugs; one double rheostat for controlling the exciter and generator fields respectively; one voltmeter plug switch; two vacuum breaker generator field plug switches; two double-pole double-throw switches—one for exciting the auxiliary generator field from the rotary and the other for exciting it from its own exciter; and ten single pole fuse blocks. The latter are the equivalent of dynamo changing switches on the dynamo, transformers and line. They



ROTARIES, GENERATOR, SERVICES AND TRANSMISSION CIRCUITS

DRAWING SIX.

are arranged with a double set of four 'bus bars each and are never handled when alive. The two sets of 'bus bars are for light and power respectively, and the idea of arrangement is to economize space by avoiding the use of a separate panel for each of the sixteen circuits.

Panel 2, which is the 2400-volt power panel, carries two 100-ampere ammeters; one four-pole double break plunger type high tension vacuum switch for the main line; and eight single-pole fuses as above. The auxiliary generator panel (No. 3) is a duplicate of Panel 2. Panel 4, the 2400-volt lighting panel, carries two 100-ampere ammeters, two double-pole single-throw plunger type switches and eight fuse plugs. From this panel two circuits run out as single-phase mains through Stilwell regulators, as shown in Drawing Six. This panel also supports a swinging arm carrying two voltmeters. Panel 5 is for the 500-volt rotary. It carries one 11-ampere ammeter in the rotary's field, one 600-ampere ammeter in one phase of the alternating-current side, two synchronizing lamps, one field rheostat in the shunt field, one four-pole switch for the induction motor used in starting, and one four-pole two-phase main switch. The 250-volt rotaries are on Panels 6, 7 and 8, the equipment of which are identical with that of Panel 5, except in that the ammeters have ranges of 25- and 1200-amperes respectively. Panel 6 is mainly for the 400-kilowatt rotary, and Panels 7 and 8 are for the two 225-kilowatt rotaries respectively, and they differ only in the range of the instruments.

The 500-volt service is handled by the switchboard facing the 500-volt rotary, or to the left of the direct-current end of the third rotary shown on page 96. Panel 1 is the main panel, and carries an ammeter, voltmeter, circuit breaker and double-pole double-throw switch. Panel 2 is the railway feeder panel, carrying two ammeters, one for the power and one for the railway circuit; one wattmeter on the railway circuit and one double-pole double-throw switch for throwing the two sets of 'bus bars in multiple. Panel 3 carries the red-handled switches for throwing the two 250-volt rotaries in series, as well as being the railway distributing panel. Its appliances are: One ammeter; two double-pole double-throw distributing switches for the railway feeder; two wattmeters, and three single-pole single-throw red-handled switches. Panel 4, called the San Gabriel feeder panel, carries two 500-ampere ammeters and two double-pole double-throw switches for the two sets of 'bus bars on the back of the board. In addition, each of the above four panels has a voltmeter plug switch.

The low tension or three-wire distributing switchboard appears at the left of the interior view referred to, and the first seven panels from the front control seven separate feeders. The appliances on each panel are a pilot lamp, a direct-current ammeter in each three-wire outside lead, a circuit breaker in each outside lead, a voltmeter plug switch, a three-pole single-throw switch controlling the three wires—positive, negative and neutral. This last switch appears only on Panels 1, 2, 5 and 6, while Panels 3, 4 and 7 have only double-pole single-throw switches, the neutral point being omitted. The voltage of these panels is read from swinging Weston voltmeters at the end of the board.

Panels 8, 9, 10 and 11 are for the 250-volt rotaries; the first two being for rotary No. 1, and the last two being for rotary No. 2. Two other panels are to be added for the 400-kilowatt rotary. These panels carry a pilot lamp, a 1500-ampere Weston ammeter, and a main circuit breaker, thus having an ammeter and circuit breaker in each lead of the direct-current side of the rotary. Voltmeter plug switches are in panels 8 and 10, which also carry at the bottom left hand side a locking field switch by means of which the rotary may be either separately excited from the 'bus bar or self-excited. In the center is the main switch in the positive leads. Panels 9 and 11 carry at the left the main neutral switches, and at the right the main switches in the negative leads. In the rear of these panels is the water rheostat used in starting the rotaries from the direct-current side.

The local distribution follows the standard Edison practice closely, differing therefrom only in the use of creosoted wooden ducts instead of Edison tubes. There are sixteen different centers of distribution in the underground conduit area, all of which are reached by 500,000 circular mil cables or 200,000 circular mil mains. Rubber covered wire is used exclusively, and both the 500-volt and 220-volt direct-current services are underground. The neutrals are all connected solid, but the outside wires are fused through a reliable street fuse box designed and built by the San Gabriel company. Manholes are made in the streets as required, and service boxes are placed in front of each separate property. No boosters are used at present, but when it becomes necessary to do so, one of the smaller rotaries will be used as a booster.

At various portions throughout this article are presented characteristic curves concerning generators, transformers or rotaries. These are self-explanatory, but it should be stated regarding them that they were taken by Mr. H. P. Reed, acting as consulting electrical engineer for the San Gabriel company, in order to determine if the apparatus furnished conformed to the specifications under which it was bought. For several years Mr. Reed was employed in the testing department of the General Electric Company at Schenectady, which position he left to enter the employ of the San Gabriel company, but before coming to California he went to Pittsburg where he submitted the apparatus to an elaborate series of tests, a brief portion of which is here incorporated. Mr. Reed's long experience in this line of work leaves no room for doubt as to his competency in testing the forms of equipment submitted to him as well as bespeaking the accuracy of the results.

There is little to be said of the principals of the San Gabriel Electric Company beyond reference to Mr. W. G. Kerckhoff, its president, and Mr. A. C. Balch, its vice-president and general manager, upon whom have fallen the financial and commercial responsibilities of the enterprise. However, particular reference should be made of the fact that the equipment of the sub-station was erected under the direction of Mr. E. W. Crane, while that of the power house was erected in charge of Mr. Phil. S. Taylor, both acting in the employ of the Westinghouse company. When operations began, Mr. Taylor took charge of the sub-station, relinquishing the power house to Mr. Crane, each of whom will probably remain with the plant until winter is over.

PERSONAL.

Of those who have been identified with the engineering features of the work, especial credit should be given to the engineering services rendered by Mr. A. C. Balch, general manager and chief engineer of the San Gabriel Electric Company, Mr. R. S. Masson, electrical engineer of the Pacific Coast office of the Westinghouse Electric and Manufacturing Company, and to Mr. G. O. Newman, engineer-in-charge of the hydraulic development and installation. Mr. Masson requires no introduction to the readers of these columns and an instance of his high attainment as an electrical engineer is found in the statement that to him is due the working out of the ingenious combination above described by which the two 225-kilowatt rotaries are run in series. Mr. Newman has been chief engineer of the Riverside, Cal. Water Company for twelve years and he is recognized as being one of the most proficient engineers in the development and measurement of water to be found in the west.

Mr. Balch first came prominently before the electrical world through his association with the Union Power Company, of Portland, Or., in which, as installing engineer for the Portland office of the Edison General Electric Company, he erected the first electric railway system operating under the Edison three-wire system. In this case, the power plant was located some three miles from the distributing point for the two railways to be operated and distribution at 500 volts, in accordance with the then existing practices, would make the investment in line almost prohibitive. Accordingly it was determined to use the Edison three-wire system, feeding one railway from its positive side, the other railway from the negative side and grounding the neutral. The undertaking proved eminently successful and saved tens of thousands of dollars in copper alone.

To be more explicit as to Mr. Balch's engineering record: He

was born on the 13th of March, 1864, near Troy, N. Y., and, in the fall of 1885, entered Cornell University, at Ithaca, N. Y., whence he graduated in 1889 upon completing the course in electrical engineering. During the summer of 1888 he was with the Mather Electric Company at Manchester, Conn., and also was engaged in installing the Mather electric lighting plant in the factory of the American Watch Company at Waltham, Conn. After graduation, Mr. Balch came west to Seattle, Wash., where he engaged in partnership with Mr. Charles H. Baker, (now president of the Snoqualmie Falls Power Company) doing a general engineering business under the firm name of Baker, Balch & Co. About this time Mr. Balch installed the central station plant of the Pacific Electric Company, afterwards consolidated with the Commercial Electric Company and known thenceforth as the Home Electric Company. This was later consolidated with the Seattle Gas and Electric Company, the new plant being called the Union Electric Company. Mr. Balch was engineer in entire charge of these plants until just previous to the formation of the Union Electric Company, and shortly thereafter he went to Portland and entered the service of the Edison General Electric Company as stated. His installation of the three-wire system in the Union Power Company's plant for the operation of railroads and electric power, was an achievement that had been up to that time unequaled in railway work, and, in fact, a marked characteristic of Mr. Balch's engineering career has been a boldness that, when tempered with the sound business judgment and his thorough proficiency as an engineer, has made his every undertaking successful. In October, 1891, Mr. Balch became the electrical engineer of the Union Power Company, and in September of the year following he took a lease of the entire plant, operating it until 1896, when he sold it to the Portland General Electric Company. While in Seattle he secured the franchise in Tacoma afterward utilized by the Commercial Electric Light Company, which purchased the franchise and the partly constructed plant from Mr. Balch. He also installed the central station plant at Blaine, Wash., for Mr. L. H. Griffith. After selling out the plant of the Union Power Company at Portland, Mr. Balch moved to Los Angeles, Cal., where, within a comparatively short time after his advent in that city, he organized the San Gabriel Electric Company, the completion of which attests his engineering and business ability.

All of the electrical equipment of the entire plant from the power house to the lighting and power services, was built and installed by the Westinghouse Electric and Manufacturing Company, with one or two minor exceptions, notably in the use of a few Weston instruments and in the fact that the bulk of the arc lighting is done by enclosed lamps of the "Jandus" and "Pacific" types. The copper for the transmission lines was furnished by the Washburn & Moen Manufacturing Company, that for the underground distribution by the John A. Roebling's Sons Company. Locke triple petticoat glass insulators are used throughout. The Paraffine Paint Company supplied the P. & B. paint used on the cross arms and in the underground work, while the redwood stave pipe along the waterway was built and installed by the Excelsior Wooden Pipe Company, 204 Front street, San Francisco. As previously stated, the water wheels, governors and hydraulic equipments were built and installed by the Oakland Iron Works, of Oakland, Cal. All the tunnel and rock work along the waterway was done by Messrs. Keating Bros., well known contractors of Los Angeles.

DATA OF THE HYDRAULIC AND ELECTRICAL EQUIPMENTS OF THE SAN GABRIEL ELECTRIC COMPANY.

WATER SYSTEM.

Catchment Area: 23 square miles.
Maximum Flow: Flood flow, 30 feet deep where gorge width is 400 feet.
Normal Minimum: 1700 miners inches in surface flow and estimated underflow.
Capacity of Ditch: 4600 miners inches.
Characteristics of Construction: Solid concrete or pipe line throughout.
Length of Ditch: 31,400 feet.
" Tunnels: 20,697 feet.
" Wood Pipe: 8872 feet.
" Steel Pipe in Ditch: 300 feet.
" Concrete Culvert: 1551 feet.
Average Gradient: 5 feet per mile.
Average Speed of Flow: 4½ feet per second.
Gradient of Tunnels: 5.28 feet per mile.
Gradient of Wood Pipe: 10.92 feet per mile.
Width of Tunnels: 4 feet, 9 inches in the clear.
Height of Tunnels: 6 feet to crown of arch.
Depth of Water in Tunnels: 4 feet.
Wood Pipe Material: Selected redwood.
Staves: 6 in. wide; 2 in. thick before rounding; after rounding, 1¾ in. +.
Bands: ½ inch round, wrought iron.
Diameter of Wood Pipe: 48 inches.
Bends in Pipe: No. 8 riveted steel pipe, 50 inches in diameter.
Lumber in Pipe: 221,800 board feet.

PRESSURE PIPE LINE.

Length: 827 feet.
Average Gradient: 45 degrees.
Diameter: 36 inches, except in upper course of 6 feet, which tapers from 36 to 48 inches on entering penstock.
Material: Riveted steel.
Lengths by Gauges: 197 feet No. 11; 164 feet No. 5; 164 feet No. 0; 302 feet No. 0000, enumerating from upper course.
Anchors: 7 in number, placed equidistant along pipe line, and each consisting of 15 feet of concrete work on bedrock.
Safety Devices: Two 6-inch air valves in pipe line; two 3-inch "spring loaded" relief valves on receiver, which also has one 4-inch blow-off at lower end.
Receiver: Length, 40 feet; diameter, 48 inches; of ½-inch riveted steel.

WATER WHEELS.

Type: Tutthill, impulse.
Number of Wheels per Set: 2.
Number of Sets: 4.
Capacity per Set: 550 porse power.
Number of Nozzles per Wheel: 1.
Weight of Flywheel: 6000 pounds.
Speed: 430 revolutions per minute.
Coupling: Flexible leather link.
Buckets: Cast-iron, on alternating sides.
Efficiency: Above 82 per cent.
Governors: 2, Tutthill type.
Manufacturers: Oakland Iron Works, Oakland, Cal.

ELECTRICAL EQUIPMENT.

Azusa Power House. Generators: Four 300-kilowatt, 2-phase, 400- to 500-volt Westinghouse machines, running at 430 revolutions per minute.
Exciters: Three 7½-kilowatt, 110-volt 4-pole machines, running at 1300 revolutions per minute, and belt-driven from generator shaft.
Frequency: 50 cycles.
Transformers: Four 250-kilowatt, oil-insulated, air-cooled Westinghouse, stepping-up from 400 to 500 volts primary 2-phase, to 15,000 to 17,000 volts secondary, 3-phase, by the Scott system.

POLE LINE.

Length: 23 miles.
Line: Two 3-phase, 3-wire circuits, of No. 5 hard drawn copper.
Insulators: Locke, 5½-inch glass.
Separation Between Wires: 24 inches on the sides of the equilaterals.
Cross Arms: Wood, painted with P. & B.; length of upper arms, 6 feet; length of lower arms, 8 feet.
Pole Lengths: Within city limits of Los Angeles, 50 feet; outside city limits, 40 feet. Poles are of Oregon pine, with butts asphalted. At crossings, 50-foot poles with double arms framed.
Pins: Locust, boiled in paraffine and painted with P. & B.
Transposition: Each 3-phase circuit is spiralled one complete turn, the two circuits being spiralled in opposite directions. Each line is ⅓ spiralled 7¾ miles from Los Angeles and 7¾ miles from Azusa.
Telephone Circuit: Iron; transposed every 5 poles; on brackets on same side of poles, from 3 feet to 10 feet below power lines; induction inappreciable.

ELECTRICAL EQUIPMENT.—LOS ANGELES SUB-STATION AND PLANT.

Transformers, by Capacities: Two 125-kilowatt, reducing from 15,000 to 2400 volts; two 150-kilowatt, reducing from 15,000 to 360, 375, 425, or 460 volts; and four 125-kilowatt, reducing from 15,000 to 218 volts; two 150-kilowatt, reducing from 15,000 to 2400 volts, together with four series transformers used for regulating purposes. Total capacity, ten transformers, 1750 kilowatts.
Type of Transformers: Westinghouse, oil-insulated, air-cooled.
Generator: One 300-kilowatt, 2400-volt, 2-phase, 50-cycle, rope-driven, Westinghouse, at 430 revolutions per minute.
Exciter: One 7½-kilowatt, 110-volt, 4-pole Westinghouse, at 1300 revolutions per minute.
Rotaries: One 250-kilowatt, 500 to 550-volt D. C., transforming from 360, 375, 425, or 460-volt A. C., or vica versa, at 500 revolutions per minute; two 225-kilowatt, 220-320-volt D. C., transforming from 218-volt A. C., or vica versa, at 500 revolutions per minute; one 400-kilowatt, 220-320-volt D. C., transforming from 218 volts A. C.

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EDITORIAL.

POLYPHASE CURRENT DISTRIBUTIONS.

The relative merits of two and three phase current distributions are discussed by Mr. Andrew Stewart in a recent issue of *Electricity*, London, who in answer to a question as to the conditions under which it is desirable to choose a two or three phase system, points out that the fact that both are successfully supplying light and power from the same circuits does not mean that they are equally suited for the purpose. The author does not agree with the statements made by the advocates of three-phase currents that three-phase motors give a more uniform torque and a higher power factor than two-phase motors, and after discussing the liability of the three-phase system to become unbalanced, reaches the conclusion that the necessity for maintaining a well-balanced line renders it unsuitable for the general distribution of light and power when both characters of service are delivered from the same circuits. It is impossible to control any one phase of a three-phase circuit independent of the other two phases, because the three circuits are electrically interlinked, hence the application of the three-phase system seems to be confined to simple power distribution in large units, or to any purpose where the current may be kept approximately the same in all three lines.

Two-phase presents many advantages, especially where single-phase is already installed, as it is easy to feed a single-phase network, as such, from a two-phase generator; there is also an entire absence of balancing troubles, as a two-phase generator may be run with one phase fully loaded and the other half loaded, with scarcely any variation of the pressure, while even this may be eliminated by regulation. The ease with which one phase may be controlled independent of the other renders it extremely useful in supplying a mixed system of light and power, as in such cases it would be practically impossible to get the load equal on both phases. Nearly all the regulating devices used on single-phase may be used on two-phase, thus rendering easy its introduction into places where single-phase is already installed. Indeed, two-phase seems to give all the advantages of multiphase distribution, with the flexibility and ease of control so characteristic of two-phase.

In factories where the distribution of light and power by polyphase currents has been coming to the front of late, there seems in many cases little to choose between two and three phase currents. In most cases a large motor load has to be supplied, and as the lighting load goes on and off with fair regularity, and is generally under the control of the engineer in charge, unbalancing troubles are not so much to be feared. Thus three-phase meets all requirements. However, electric welding has to be considered, and as it is desirable, wherever possible, to use only one type of plant inside a works, the suitability of the generator to supply current for welding transformers is important. Here two phases scores decisively. It is a matter of no difficulty to supply a welding transformer from one phase of a two-phase generator, while to do the same from a three-phase generator would be to upset the balance of the entire system, causing lamps on one side of the network to burn dim, arc lamps to flicker, and a general derangement of the entire system.

One important point should not be overlooked, that is, cost of copper. This is greatly in favor of three-phase, while on the basis of maximum stress on insulation, the direct current, three-wire system is most advantageous. Although three-phase has such a large advantage over its rivals in the matter of cost of copper, this does not have much influence in the cost of power transmission in factories, where the cost of copper seldom exceeds 30 per cent. of the total cost, and when compared with flexibility and ease of control of two-phase, it will be no great advantage to give three-phase the preference, except where very large amounts of power must be transmitted.

It will be seen from the foregoing that both systems have distinct merits of their own, and in course of time each will have its own position in the engineering world.

THE SNOQUALMIE PLANT.

The opening month of the new year will witness the inauguration of two noteworthy transmissions, the first of which will probably be that of the Southern California Power Company, with its eighty-mile, 33,000-volt line into Los Angeles, and closely following which will be the starting of the transmission of the Snoqualmie Falls Power Company into Seattle and Tacoma. This plant is of especial interest because of its high voltage, its capacity, and its use of aluminum wire—the Snoqualmie company being the first to use aluminum on a long distance power transmission line. A statement of the present condition of the work is therefore of timely interest.

The pole line will be completed from Snoqualmie Falls to Seattle, a distance of thirty-one miles, about December 15th. The poles will carry six wires, each 263 mils in diameter, arranged in two three-phase circuits, one on

each side of the pole, and each circuit being in the form of a triangle having thirty-six-inch sides. One of the circuits will be spiralled at six points between the Falls and Seattle, the object being to obtain two changes in the arrangement of the wires between the Falls and the three points at which the circuits will be tapped. Aluminum wire is shipped in lengths of approximately 1500 feet and joints in it are made with a tubular sleeve slipped over the two ends and firmly twisted. The elastic limit of the size of wire used, which is equal in conductivity to No. 4 B. &. S. copper wire, is 800 pounds, and all tests have shown the sleeve joint to be stronger than the wire proper. This wire has a conductivity of sixty per cent. of that of copper of equal cross section, and its weight is about one-half of that of No. 4 copper wire. The Snoqualmie company is using No. 8 B. & S. aluminum for tie wires, and No. 10 aluminum for the telephone circuits. The Redlands type of porcelain insulator is used; the locust pins have five inches of pin between the base of the insulator and the top of the arm, and all pins were boiled in oil. The step-up transformers are adapted to deliver current at an electromotive force of 14,500 or 15,000 volts, and 2,000 and 30,000 volts. The two circuits to Seattle are planned to deliver 4000 kilowatts at 25,000 volts with a loss of fifteen per cent. of the energy delivered.

The transmission line to Tacoma, on which work has not yet been commenced, will parallel the Seattle line, at a distance of forty feet therefrom, for nineteen miles from the Falls, at which point all the circuits will be taken to a plug switchboard to give all possible interchangeability in case of trouble on one of the circuits. From this common point the line will be constructed to Tacoma, a further distance of twenty-six miles. Drawn on paper, the two lines form a Y with the left hand upper portion some fourteen miles longer than the upper side. The common point is Renton, a small town at the south end of Lake Washington, and where it is proposed to install a substation for a local distribution. The Tacoma line will also carry two circuits that will be similar in all respects to the Seattle lines except that the aluminum wire will have a diameter of 233 mils. This line will probably not be erected until the severity of winter has passed.

It has already been stated in these columns that the generating equipment will consist of four 1500-kilowatt, 1000-volt, revolving armature, three-phasers. There will also be twelve 500-kilowatt raising transformers and a practically equal capacity in lowering transformers of 300 kilowatts and 500 kilowatts each, to suit the local requirements. The comparatively high transmission frequency of 7200 alternations has been selected with reference to furnishing alternating current arc lighting. The first generator was shipped on November 15th and it is expected that the Seattle line will be put in service on January 15th, which is the date fixed for the operation of the Centennial Flouring Mills from two 200 horse-power induction motors.

The Snoqualmie plant will be the second great transmission in the Pacific Northwest—that of the Portland General Electric Company being the other—but the fewness of noteworthy transmissions within its borders must be attributed to cheap fuel and not to lack of enterprise on the part of the local engineers, nor to any inappreciation of the value of the numerous water powers there to be found. High voltages for transmission purposes and the ability to apply electrically transmitted energy to almost every conceivable purpose with equal if not greater satisfaction and reliability than is possible from any other source, have together combined to make such transmissions possible in a country where coal and wood fuel abound.

Passing Comment

An Editorial Review of Current Events and Comtemporary Publications.

NOTEWORTHY CURRENT TRANSFORMATIONS.

The remarkable combinations that have been used by the San Gabriel Electric Company, as described in the leading article of this issue, makes especially interesting the contribution of Mr. Charles F. Scott on "The Evolution in Central Station Practice" appearing in *The Engineering Magazine* for November, in which is described as typical instances of the flexibility of polyphase currents, the transformation of current as practiced at Niagara Falls and at Hartford. Without doubt, the San Gabriel transmission must now be enumerated in the list of the world's most noteworthy current-transformation installations, for while its electrical combinations are not as numerous as are those of Niagara, they are more so than at Hartford, and they are equally if not more heroic than the combinations of either plant separately.

Mr. Scott's article produces an interesting diagram showing the transformation of current from the two-phase generators at Niagara Falls. All the power from the 5000 horse-power generators is delivered as two-phase alternating current, at 2000 volts and a frequency of 25 periods per second. Four wires are carried directly from the generators to the surrounding establishments. Current is transformed to low voltage and then converted into direct current at 550 volts for railway service. It is also converted into direct current at 160 volts for use in the production of aluminum. Elsewhere it gives direct current at variable voltage, adjustable at will from 125 to 165 volts in one case, and from 170 to 230 volts in another, to meet the varying requirements of electrochemical processes. It is used as alternating current at low voltage for producing intense heat in chemical manufacture, in some places at a constant voltage, and in another at variable voltage. Regulators are provided by which 1000 horse-power can be delivered in the form of 3750 amperes at 80 volts or any intermediate current and corresponding voltage. The current supplies induction motors of 400 horse-power and smaller sizes, some for replacing engines in lighting stations, others for doing various work in factories, sometimes directly at 4000 volts, sometimes at low voltage.

The current is transformed into three-phase current at

11,000 volts for transmissions to greater distances. At Tonawanda there are rotaries for delivering direct current to the Niagara and Buffalo railway, and there are distributing circuits for supplying electric current for power and light. At Buffalo current is reduced in pressure and converted into direct current at 550 volts for street railways and for stationary motors. It is converted into direct current for 220-volt three-wire distribution; it runs motors which replace engines in lighting stations for driving dynamos for arc lighting and for high frequency incandescent lighting; it runs motors in grain elevators and various industries and supplies incandescent lighting.

At Hartford, Conn., are two sources of power—a water-power, ten miles from the city, which drives alternating current generators delivering current through raising transformers to a three-phase 10,000-volt transmission circuit and to a steam engine located in the city. This engine drives a countershaft from which are belted a number of arc machines, the countershaft is connected to an alternating current machine which may be driven by the engine for supplying power to the alternating circuits, or this machine may receive current from the transmission line and run a synchronous motor, driving the countershaft and arc machines. There are rotary transformers in the city which receive alternating current either from the water-power station or from the steam station, and deliver this power in the form of direct current which is supplied either to the 220-volt three-wire distributing system or to a large storage battery. The storage battery may, in turn, serve as a source of power, from which current may feed into the direct current distributing system; or, passing through the rotary, it may appear in the form of alternating current which may either supply the alternating current distributing circuits, or pass to the sychronous motor and be used for arc lighting.

Either the water power or the steam engine of the Hartford plant may, therefore, supply either the arc circuits, the alternating circuits, the direct current circuits or the storage battery. The latter may in turn supply power to any of the three classes of distributing circuits. The storage battery is charged when the load upon the distributing circuit is small and it discharges when the demand is greater than the capacity of the water-power station, thus enabling the turbines to carry a load of some 50 per cent. above their maximum output. The battery is also a useful regulator for both direct and alternating circuits, to prevent variations of voltage with varying load. The steam plant is a reserve.

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"SYNCHRONOUS VS. INDUCTION MOTORS."

On page 76 of the present volume was reprinted an article under the above caption containing the following statement, which is somewhat misleading: "The ordinary method of expressing the magnitude of wattless and energy currents—namely, by the power factor percentage—is, by the way, a snare and a delusion. A power factor of 90 or 94 per cent., values often obtained with large induction motors at full load, gives the impression that the wattless currents are only from six to ten per cent. of the total, whereas, on account of the vectorial relation, the wattless currents are in the one case one-third and in the other case one-half as great as the energy currents, giving in combination with the self-induction of generators, lines and transformers, corresponding reactive voltage drops."

It is true that the components representing the wattless currents in the cases mentioned are one-half and one-third as great as the energy currents when laid off in vectorial diagrams. The wattless components, however, are at right angles to the energy currents, and therefore the actual current flowing on the line is the resultant or geometrical sum of the two currents. The actual current appearing on the ammeter is, therefore, approximately in the one case 10 per cent., and the other 5 per cent. greater than the energy current. The losses on the line due to inductance and ohmic drops would be in the proportion of 10 and 6 per cent. and not 50 and 33⅓ per cent., as implied by the above-quoted statement.

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A TELEPHONE MAGAZINE AT LAST.

After weary years of anxious waiting, the tens of thousands of electrical workers that are employed in the telephone industry have a publication devoted exclusively to telephony, and, what is of far greater import, this publication bears every evidence that it is worthy of the support of the great electrical interest it represents. The publication referred to is none other than *Electrical Engineering*, which has been acquired by new owners, principal among whom are John C. McMynn and C. E. Kammeyer, and with the change in ownership has come a radical change in policy, for *Electrical Engineering and Telephone Magazine* now openly advocates the independent telephone movement.

Congratulations are extended to the telephone interests on the appearance of so highly creditable a publication devoted to their interests.

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RIEHLE'S "DIGEST" SUSPENDS TEMPORARILY.

It is with genuine regret that note is made of the temporary suspension of *Digest of Physical Tests* with the issue for October, and the void that this suspension creates in engineering literature is one that will be hard to fill. As to the cause, the announcement is made that the many demands upon the time of Mr. Joseph W. Bramwell, editor, for new developments in the line of testing machinery, together with the general activity in the business of Riehle Bros.' Testing Machine Company, of which he is superintendent, makes a suspension imperative. The hope that the publication will soon be resumed will find its echo from all.

That THE JOURNAL'S articles on electric transmission are appreciated beyond local spheres, is evidenced by the fact that its foreign subscription list has quadrupled, and its Eastern list has increased ten-fold, in six months.

Personal

ROBERT BRUCE ELDER, who has long been recognized as one of the most successful salesmen of electrical apparatus on the Pacific Coast, entered the electrical business immediately upon graduating from the high school of his native city, San Francisco, in 1887, his first association being as draughtsman with the Electric Development Company, which held the original Edison agency for the Pacific Coast. It was through this company that Mr. J. C. Henderson, afterward chief engineer of the Edison General Electric Company, became so well known on the Pacific Coast during the early days of the electrical industry, and associated with him were Messrs. Geo. D. Ladd, Percy T. Morgan, and F. W. Eaton — all names since prominent in electrical enterprises in California. The old "Z" type, long field Edison dynamos represented the highest perfection of the art at that time, and there were installed several plants that are now looked upon with historical interest, the most noteworthy being on the San Francisco-Portland steamship "Columbia," and in the Spreckels sugar refinery at San Francisco. A year or so thereafter the alternating current system came into prominence out west, and Mr. Elder became connected with the San Francisco office of the Westinghouse Electric and Manufacturing Company almost at the very inception of its Pacific Coast agency. About the first work undertaken by it was the installation of the Westinghouse system in the Baldwin Hotel, San Francisco. Mr. W. A. Burkholder was in charge of the erection of the Baldwin plant, and young Elder's first work of a practical nature was as a wireman on the job, and the next work of prominence in which Mr. Elder was employed was the installation of the Westinghouse plant in the Southern Pacific shops at Sacramento. The organization of the Pacific Electrical Storage Company and the interest that had arisen in the storage of electricity, occasioned the next change that was made in Mr. Elder's connections, and he became associated with the new concern in the dual capacity of salesman and superintendent of installation. Mr. Frederick Reckenzaun, brother of M. A. Reckenzaun, whose names are intimately connected with the development of electrical accumulators, was the electrician of the company, but when it was found that the scheme for establishing a factory in San Francisco could not be carried out, Mr. Reckenzaun resigned and returned to the east, and Mr. Elder succeeded to his interest and position in the Pacific Electrical Storage Company. Some very interesting storage battery installations were made under Mr. Elder's direction, among which may be enumerated the Swain, Edenvale, Benicia, Reno, Fair, and Pleasanton plants. Mr. W. S. Heger, now manager of the San Francisco office of the Westinghouse Electric and Manufacturing Company, was then manager of the San Francisco office of the United Edison Manufacturing Company, and a friendship between him and Mr. Elder developed at that time which has since grown into the closest possible relations. In fact, throughout the years that intervened from the first year of 1890 to 1896, when Mr. Heger was appointed to his present position, it was the hope of both parties that they might ultimately be associated together, and this desire was gratified when, in September, 1896, Mr. Elder became identified with the San Francisco office of the Westinghouse Electric and Manufacturing Company. His success as a salesman in this capacity has been remarkable, and one of the many evidences of his ability in this direction rests in the fact that he carried on the negotiations and executed the contract resulting in the sale of Westinghouse apparatus exclusively for the use of the San Gabriel Electric Company's Azusa-Los Angeles transmission, so fully described in this edition. Mr. Elder is of the character best described as bright and clear cut, and these qualifications, coupled with a merry, pleasing personality and a sound judgment of engineering matters, combine to make him what he is: one of the most agreeable and successful salesmen to be found in the electrical business.

ROBERT BRUCE ELDER.

PROF. A. VAN DER NAILLEN, president of the Van der Naillen School of Engineering, San Francisco, has returned from a six months' trip through the continent of Europe, whither he went to study the most recent advances that have been made in electrical science since his last visit there, less than two years previous. As a portion of the fruits of the trip, the class in electrical engineering of the Van der Naillen school is to be equipped with considerable new electrical apparatus, not the least interesting among which is the Marconi system of wireless telegraphy.

MR. I. C. WOODWARD has resigned the managership of the electrical department of the Dunham, Carrigan, Hayden Company to accept the position of sales agent for the Pacific Arc Lamp Company of San Francisco.

MR. ROBERT MCF. DOBLE has been appointed consulting and supervising electrical and mechanical engineer for the Mount Whitney Power Company, with headquarters at the company's offices, 202 Sansome street, San Francisco.

MR. C. P. GILBERT, the well known organizer and past president of the Pacific Coast Electric Transmission Association, has resigned the general managership of the Sacramento Electric Gas and Railway Company and has accepted a like position with the Standard Electric Company of California, with offices in the Crocker Building, San Francisco.

MR. A. M. HUNT, who retired from the firm of Hasson & Hunt to accept the engineership for the department of navigation of the Alaska Commercial Company, has returned from Alaska, whither he went in February last. He will not return north until next spring, if then, and will probably spend a portion of the winter in the eastern states.

MR. C. E. DUTCHER, the well known electrical engineer, has been appointed engineer for the Comstock Mining Association,

and the duties of the position, which will require all his time, have necessitated his removal to Virginia City, Nevada.

MR. ALBERT GALLATIN, vice-president of the Sacramento Electric Gas and Railway Company, will hereafter execute the duties of general manager of that corporation, vice Mr. C. P. Gilbert, who, as stated elsewhere, has resigned.

MR. J. W. HORNER, has resigned his former position with the San Francisco office of the General Electric Company to accept that of traveling salesman for the Brooks-Follis Electric Corporation.

Transmission

THE RATIOS OF ROTARY CONVERSIONS.

ACCORDING to Professor S. P. Thompson in a paper on "Rotary Converters," read before the Institution of Electrical Engineers, London, November 10th, if direct-currents are supplied at a constant pressure of 100-volts at the brushes of the direct-current side of a rotary converter, the voltmeter readings at the alternating-current side will be as follows:

Number of Collector Rings.	Angle of Connection to Rings.	Nature of Service Generated.	Voltage Ratio.	Virtual Volts.
2	180°	Single-phase	$\frac{1}{\sqrt{2}}$	70.71
3	120°	Three-phase	$\frac{1}{2}\frac{\sqrt{3}}{\sqrt{2}}$	61.23
4	90°	Two-phase	$\frac{1}{\sqrt{2}}$	70.71
4	90°	Four-phase	$\frac{1}{2}$	50.00
6	60°	Three-phase	$\frac{1}{2}\frac{\sqrt{3}}{\sqrt{2}}$	61.23
6	60°	Six-phase	$\frac{1}{2\sqrt{2}}$	35.35

A very complete discussion of these voltage relations, with formulæ applicable to the cases of open-coil windings as well as of closed-coil windings, was given by Herr R. M. Friese in the *Elektrotechnische Zeitschrift* of February 15, 1894, throughout which the author assumes the sine values of the distribution of the magnetic flux around the periphery of the armature. More recently Mr. Steinmetz has reconsidered the same problem in the same journal in articles which appeared on March 3d and 10th, 1898. Professor Thompson states that from the theoretical conditions there given, it is easy to compute not only the voltages in the several cases, but also to calculate the corresponding relative values of the working currents in the armature and line wires.

AN EXPONENT OF PROGRESS.

A well known scientist, than whom none on the Pacific Coast is more thorough, whose writings have appeared in the very best magazines the country over, and who, presumably, would prefer that his name be withheld, has written the following very gratifying letter to the editor of this magazine:

I am leaving the Coast this week, and before going, I had hoped to find time to call on you; but this will not be possible now. Something I must say to you, however, and that is that you should know how a layman regards your work in connection with THE JOURNAL OF ELECTRICITY. The magazine is a credit, not to the Coast alone, but to the whole country, and I trust it may maintain always its present high standing. I have many journals, in fact my desk overflows with them, but few of them have given me the downright information and instruction that the JOURNAL has. Great are the problems in electrical engineering yet to be tackled and mastered on this Coast. May you be, as now, an exponent of progress in this direction.

Literature.

"Electricity in the Diagnosis and Treatment of Diseases of the Nose, Throat and Ear." By W. Scheppegrell, A. M., M. D. With 161 illustrations. Published by G. P. Putnam's Sons, New York, 1898. 8vo. of 371 pages; 13 pages Bibliographical references; 18 pages index.

So many volumes of trash on "Electro-Therapeutics" have passed through our hands that even the publishers' name on the title page of the present volume was not enough to remove the preparatory feeling of repugnance with which this work, one of the most recent in electro-therapy, was taken up for review. But the excellent quality of the contents came as a most refreshing change and pleasant surprise. So great has been this feeling of pleased relief that we are in danger of forgetting to temper the praise which we would bestow with the word or two of unfavorable criticism which is indicated. Let us be done with the adverse criticism first and then resort to the more pleasant task of noting the excellent features of the work. The same old fault of printing cuts taken bodily from manufacturers' catalogues, without even effacing the dealer's name from the cut, is found in this as in all other books on electro-therapeutics which we have ever seen. Why such cuts should be used is a mystery not yet solved; it can not be the question of expense, for the added expense of making new cuts would be but a trifle in comparison with the total cost of the book. These cuts are always poor in quality and ugly in appearance, and so detract much from what would otherwise be a remarkably good specimen of the bookmakers' art. There are some lapses from grammar, and one or two inaccuracies in electro-physics, but aside from these small errors the text is beyond reproach.

The author does not spend too much useless space on the consideration of questions in electro-physics, but goes into them deeply enough for anyone not undertaking the study of electricity as a branch of science. The first ninety-seven pages are devoted to considerations of the various apparatus and the relative value of different forms and makes. It is indeed pleasant to note that he has strongly advocated the use of the direct incandescent lighting circuit, by means of proper apparatus, for all forms of therapeutic work. And his discussion of this question alone is a clear indication that he is fully acquainted with the subject on which he writes. The relative values of the various makes of cells are given, and the results of careful tests of apparatus and measuring instruments are also included in this portion of the work. Forty pages are devoted to the question of "Transillumination" as employed in the diagnosis of disease of the maxillary sinus and to the subject of the electro-cautery. The following pages deal with cataphorisis, interstital electrolysis, electro-magnetic appliances, (including magnetic laryngeal tube extractors, drills, motors, mechanical nasal saws, devices for mechanical massage of the ear and larynx, etc.) tumors of the nose, throat, larynx, and naso-pharynx, diseases and deformities of the nose, diseases of the tonsils, neuroses, and application of electricity to the ear. The last twenty-five pages are devoted to an excellent consideration of the X-rays.

One of the most valuable features of the book is the bibliographical index; the author has here enumerated 565 books or articles on the subject of electro-therapeutics, with especial reference to the specialties on which he is writing. The book is written in a clear, exact, methodical style, with copious references to the work and experience of others; it carefully considers and sifts the vast amount of matter that has been printed on the subject, and the conclusions reached are founded on experience and data, rather than upon enthusiasm and ignorance, as is the general rule. The total result of medical research in the lines embraced by the author, is represented in this one volume. It is one of the very few books of the year that are of any value.

PHILIP MILLS JONES, M. D.

Mining

ELECTRICITY IN MINING.—V.*

DIRECT current machinery is used more extensively in mining operations at the present time than is the apparatus of the alternating or polyphase types, and this is due to several reasons, principal among which are the facts that direct-current machinery was introduced and practically perfected before the principles underlying the operation of alternating-current machinery were discovered; and that alternating or polyphase motors, though highly efficient and embodying the acme of perfection in many mechanical and electrical standpoints, have not been widely installed for the operation of mining hoists owing to the fact that they are inherently so constituted that they work to a disadvantage under unsteady or intermittent loads. Of late, however, these inherent difficulties are being rapidly overcome as will be shown during the progress of this series of articles, but the purpose of the present contribution is to discuss the uses of direct-current apparatus as applied to a typical California mining installation.

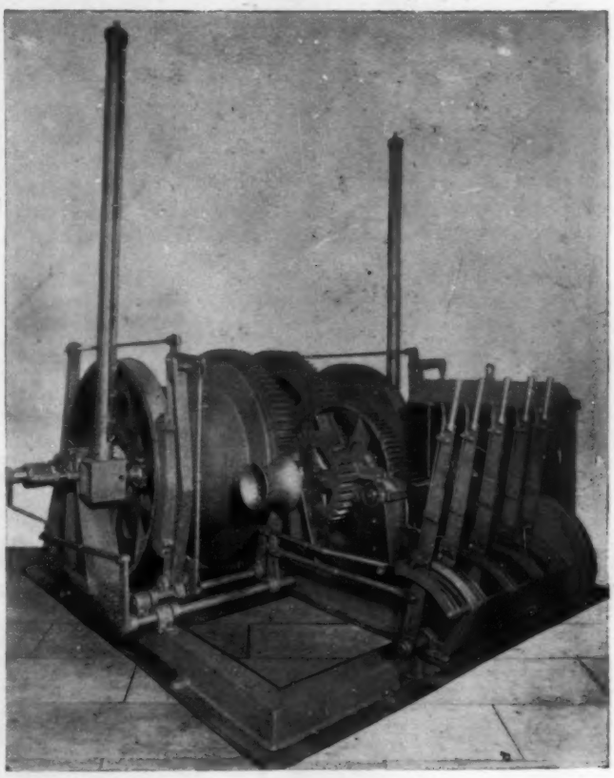
FORMERLY THE ZANTGRAF MINE.

THE MONTAUK GOLD MINE, EL DORADO COUNTY, CAL.

A reason for the success which has attended the operation of mining hoists from direct-current motors is found in the properties it possesses of running at practically uniform speed independent of its load, of taking current in almost direct ratio to the load, and of being under perfect control as to speed and direction of rotation. On the other hand, difficulties in commutation prevent the long distance transmission of electric power by direct currents and limits their sphere of usefulness to within a few miles at best from the power plant, for without high potential, transmission over material distances is commercially impracticable owing to the prohibitive cost of copper necessary to carry the low tension current.

Direct current is, therefore, eminently suited for duty within a comparatively short radius from the power plant, and the plant installed by the Electrical Engineering Company, of San Francisco, in the old Zantgraf mine of the Montauk Gold Mining Company, in El Dorado county, Cal., conforms admirably to these conditions, hence a description of its electrical equipment is pertinent at this time. The generators of the Montauk mining plant are in two units, of 125 and 70 horse-power respectively, each being run at 500 volts, and each being separately belt-driven from a 36-inch water wheel. The power house is located on the opposite side of the American river at a distance of 2700 feet from the mine, and water for driving the wheels is taken from an irrigating ditch supplied from a dam across the same river below Auburn. The water is applied to the wheels at an effective head of 120 feet and is paid for at a given rate per miners inch. These generators each supply a separate circuit, one of which is of No. 0, B. & S. gauge and the other of No. 0000. Of these, principally the hoist, is run on the No. 0000 circuit from the larger generator, while the rest of the equipment is run from the smaller generator over the other circuit.

Interest in the equipment naturally centers in the hoist, a view of which is presented on page 110. On this page is a view of a similar hoist having a single motor, which is given in order to show the method of gearing used. That in the Montauk mine is a double reel hoist, the moving parts of which are mounted on a cast iron bed plate and are self-contained. The drums are 40 inches in diameter, with 24-inch face and have deep flanges to contain from 1500 to 2400 feet of three-fourths-inch rope. Each drum is independent of the other and may be thrown in or out while the gears are in motion, and, moreover, each is provided with bronze bushings which may be replaced in case of wear. The hoist is driven by two 30 horse-power motors through double reduction gearing, each armature being geared independently to secondary gear wheels which have a common shaft. As will be seen, the motors are of the bi-polar type and their fields are commutated at the controller so that the energy ordinarily



SHOWING THE GEARING OF THE MONTAUK HOIST.

*Continued from Volume VI, page 41.

lost in the rheostat in starting is thrown upon the field windings, producing a highly over saturated field, which in turn, enables the motors to deliver the high starting torque so essential in the operation of mining hoists. The levers shown at the left in the illustration enable proper manipulation of the equipment and the controller gives seven different speeds, varying the travel of the skip from 50 to 500 feet per minute.

The shaft descends at an average angle of 52 degrees and is in double compartment. The skips weigh about 1000 pounds each and have a capacity of forty cubic feet each, or about two tons of ore. Three-quarter-inch steel rope is used and the sump is now below the 800 foot level. The trip is made in less than two minutes when a single skip is being hoisted. The accompanying tables give the observed readings taken for single and double skip loads during actual service. At the start in the former the controller was thrown to the fourth notch when the current jumped momentarily to 110 amperes, quickly falling to 100 amperes and then to 90, which appears as the reading at the 800 foot level.

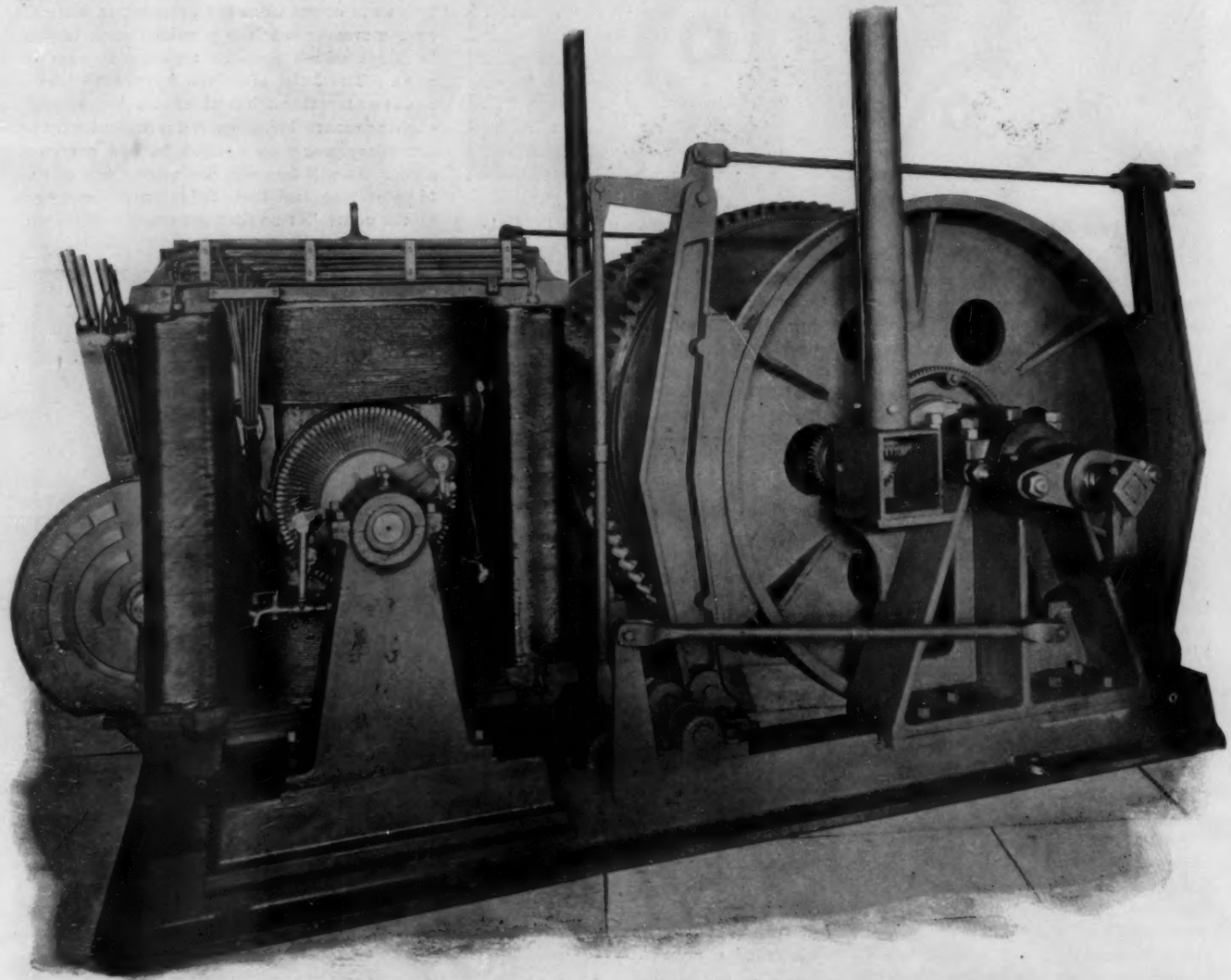
The time consumed in this trip was one minute and fifty seconds, giving an average speed to the skip of 436 feet per minute. In the other test with a double load, the start was made on the fifth point of the controller when the ampere needle jumped to 160 amperes, dropping to 120 amperes in about ten seconds, after which the readings given were taken. The time consumed with the double load was two minutes and fifteen seconds, giving a speed of 356 feet per minute.

The observed readings are as follows, Weston instruments being used:

Level	SINGLE LOAD.			DOUBLE LOAD.		
	Amperes	Volts	Watts	Amperes	Volts	Watts
800	90	450	40,500	120	400	48,000
700	80	450	36,000	120	400	48,000
600	80	450	36,000	110	400	44,000
500	70	475	33,250	110	400	44,000
400	65	475	30,875	105	410	43,050
300	60	500	30,000	100	425	42,500
200	60	500	30,000	100	425	42,500
100	60	500	30,000	90	450	40,500

In addition to operating the hoist, the 125 horse-power generator delivers current for driving a 10 horse-power motor operating a pump at the 600-foot level, and a second 10 horse-power motor which runs a rock breaker in the mill. The pump, which is of the double acting plunger type driven under double reduction, delivers water from the mine through a tunnel at the 200-foot level.

The 70 horse-power generator operates a ten horse-power motor-generator set which delivers current at 110 amperes to the incandescent circuits. A 10 horse-power motor in the pumping station in the ravine below the mill takes water from the irrigating ditch across the river and lifts it against a head of 90 feet to the mill



DRIVEN BY TWO 30 HORSE-POWER DIRECT-CURRENT MOTORS.

DOUBLE REEL HOIST IN THE MONTAUK MINE.

whence it is used as battery water; and, finally, a 40 horse-power motor is belted direct to the main shaft from which is driven the mill of twenty stamps. The managers of the property expressed the greatest satisfaction when questioned regarding the operation of the plant.

Originally the mine was driven by a 70 horse-power Corliss engine furnished with steam from tubular boilers that burned wood at $5.00 per cord, and, before the generating station had been installed, the mill motor was used as a generator by the Corliss engine, and the hoist was driven at slow speed therefrom during the period when the shaft was being sunk the last 100 feet. At that time over 50,000 gallons of water per day was being lifted from the mine. The attendance for the steam and electric plants is about equal, and while the interest on the latter is higher, the fact that the water costs only one-half as much as wood fuel formerly did, has made the change from steam to electric power a most advantageous one from every financial and operating standpoint.

Hydraulics

A THIRTY-FOOT IMPULSE WATER WHEEL.

THE perfect satisfaction which has attended the operation of the eighteen-foot water wheel installed in the North Star mine, near Grass Valley, Nevada county, Cal., in the fall of 1895, has been so great that when, a few months ago, it became necessary to increase the power plant of the North Star Mining Company, it was promptly decided that the new extension should be strictly along the lines of the old plant, so far as the type of wheel and air compressor is concerned. The entire plant as originally installed was fully illustrated in THE JOURNAL OF ELECTRICITY for November, 1895, and the present wheel, which is over half as large again in diameter as the old one, affords a striking instance of the marked advance that has been made in mechanical engineering in three years.

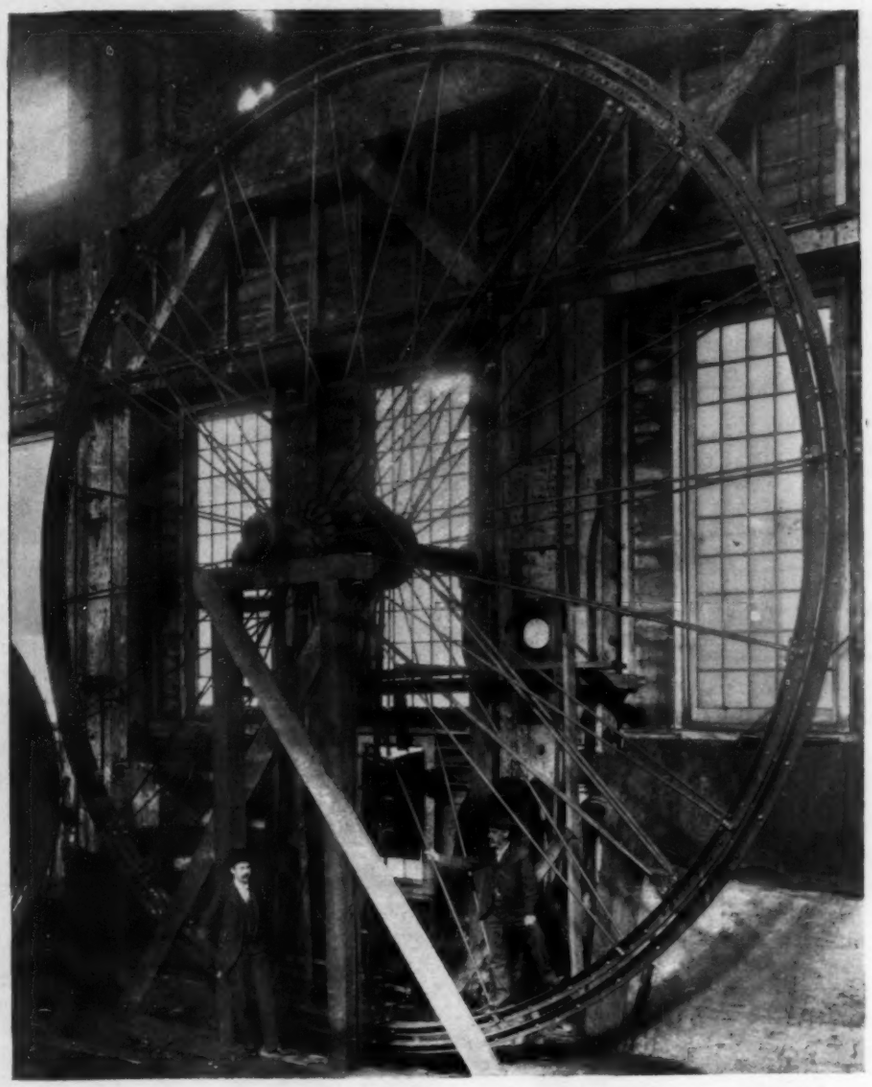
The new wheel, which is here illustrated as it appeared in the shops of the builders before shipment, is made entirely of steel except the hub, is 30 feet in diameter, and is to run at 65 revolutions per minute. It is designed to transmit 330 horse-power with one nozzle, or 1000 horse-power with three nozzles, each nozzle being 1¾ inches in diameter. The wheel operates under a head of 775 feet of water, and the power is transmitted from the rim to the hub and thence to the shaft which operates a duplex, single acting, compound air compressor. The wheel was constructed under the patent granted on August 14, 1896 to Edward S. Cobb, of the well known hydraulic and mechanical engineering firm of Cobb & Hesselmeyer.

There are several special features concerning this type of wheel that are of interest. It is perfectly adapted for use as a fly, gear, belt, or water wheel, and can be made to run any number of revolutions up to a rim velocity of 20,000 feet per minute. In the case of the present North Star wheel, the conditions required high peripheral speed, a slow number of revolutions and comparatively llght total weight. This wheel was made of 4x4½-inch angle iron in four pieces for ease of transportation, and the shop test showed that it runs true within one-eighth of an inch at the rim without being turned in the lathe.

The principal dimensions of this new wheel, as well as those of the North Star wheel installed in 1895, are as follows:

	1895 Wheel	1898 Wheel
Diameter over all	18 feet	30 feet
Width of face	8 inches	9 inches
Diameter of shaft	10 inches	10 inches
Length of hub, bore	20 inches	39 inches
Length of hub over all	29 inches	48 inches
Center to center of spokes laterally at hub	24 inches	43 inches
Center to center of truss rods at hub	30 inches	36 inches
Diameter of radial spokes	1¼ inches	1¼ inches
Diameter of truss rods	2 inches	1, 2 in. and 2, 1½ in. in each element.
Weight of rim	6800 lbs.	6000 lbs.
Weight of spokes	1500 lbs.	3000 lbs.
Weight of hub	2800 lbs.	4000 lbs.

It is stated on good authority that the cost of these wheels is very low when compared with that of other types, and the simplicity of their construction, ease of erection, and certainty of proper allowance for all stresses due to operation, make them safe and desirable wheels to use for any purpose whatever.



DIAMETER, THIRTY FEET

THE COBB TRUSS WHEEL.

They can be designed for any weight or cross section of rim and of any diameter or number of revolutions per minute. The illustration shows many details of construction which vary with the weight of wheel desired, the power transmitted and the diameter, but above all will be impressed the striking boldness of engineering which the designer evidenced in order to increase the mechanical efficiency of the combination by eliminating the losses that result from the usual methods of reducing the speed of water wheels to that required for operating the air compressor, such as through gearing, belting or rope transmission.

Industrial

In Responding to Advertisements in this Publication, please mention "The Journal of Electricity."

MINIATURE ARC LAMPS.

THE introduction of the enclosed arc lamp has extended the field of the arc system of electric lighting to interior illumination; the miniature arc of the General Electric Company promises another advance in providing for the use of arc light in smaller units so that it may compete with oil, gas, and incandescent lamps in illuminating halls, offices, display windows, and rooms of limited area.

Heretofore, arc lamps have been designed to give an intensely bright light, and they naturally required considerable current. For certain installations such lamps are not desirable. With low ceilinged rooms an intense light over-illuminates the arc directly beneath it, while other parts of the room are left comparatively dark. In the new minature arc lamps, the illuminating power and the current are much less, so that several lamps are not more expensive to operate than one large lamp; while by dividing the total amount of light required, the general illumination is greatly improved. The miniature arc lamp is also suitable for other places where a large arc lamp would supply more light than necessary. It is of the single globe and reflector type, the light of the arc being thrown down from the polished under surface of the reflector.

This miniature arc lamp, designed for 110-volt, direct current circuits, is frequently required to operate at slightly higher or lower voltages. An adjustable resistance has, therefore, been provided in the top of the casing which adapts the lamp to any line voltage from 100 to 120. The standard current required by the GE. miniature arc lamp is 2½ amperes, but a loop in the magnet coil permits an adjustment for 3 amperes. 73 to 75 volts are required at the arc, and when adjusted for 2½ amperes with a line voltage of 110, the energy at the terminals is 275 watts. Adjusted for 3 amperes, the energy is 330 watts. The life is from 40 to 45 hours with standard current, and from 35 to 40 hours with 3 amperes. The mechanism of the miniature arc lamp operates on the well known General Electric carbon feed principle. The carbon is fed through a brass tube extending through the center of the magnet coil. The double cam clutch which operates directly upon the carbon is simple in its action and has few parts. Special attention has been given to the design of the carbon holders and the general arrangement of the frame to facilitate rapid trimming.

FIGURE 1.

FIGURE 2.

The principal dimensions of the miniature arc lamp are:

Length over all	18⅛ inches
Weight	9½ pounds
Upper carbon	8⅛x⅜ inches
Lower carbon	3⅛x⅜ inches
Enclosing globe, top diameter	2 inches
" Maximum diameter	3 inches
" Bottom diameter	1⅞ inches
" Height	4 inches
Porcelain shade	11x2x2⅝ inches

Figures 3 and 4 show the striking contrast between the size of the miniature lamps and that of a lamp sold for interior illumination a short time ago.

FIGURE 3.

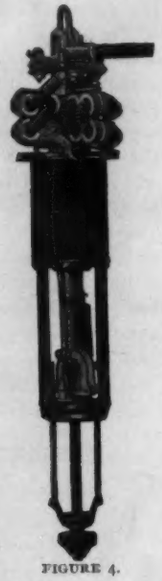


FIGURE 4.

No outer globe is used. Each lamp is arranged with a switch so that it can be readily thrown in or out of circuit.

Several hundred of these lamps have been introduced among central stations in the past sixty days, and there seems to be an increasing demand for arc lamps of small and attractive design.

MR. L. D. Tandy, of the engineering staff of the railway department of the General Electric Company, is in San Francisco and will probably remain on the Coast for several months.

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